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Grazing Method Effects on Forage Production, Utilization, and Animal Performance on Nebraska Sandhills Meadow

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Mob grazing using ultrahigh stocking densities is promoted as a tool to increase the health and productivity of grasslands by increasing nutrient cycling and soil organic matter. Mob grazing can be defined as a strategy in which area available to grazing animals is restricted to achieve stocking densities of 200,000 kg/ha or greater. Objectives of the study were to determine herbage production, utilization, and cattle weight gains among ultrahigh stock density grazing and more conventional grazing methods on a Sandhills subirrigated meadow. Treatments included two replications of each of the following: four-pasture rotational grazing with two occupations per pasture in an 80-day grazing season (4-PR-2), four-pasture rotational grazing with one occupation per pasture in a 60-day grazing season (4-PR-1), and a mob grazing system with one occupation per pasture in a 60-day grazing season (MOB). In each of the four years (2010 – 2013), yearling beef cattle grazed the 4-PR-2 from mid-May through early August and the 4-PR-1 and MOB treatments from early June through early August. Stocking rates were equal among treatments within years but varied among years dependent on forage production. Stock densities were 225,000 kg/ha, 7000 kg/ha, and 5000 kg/ha for the MOB, 4-PR-1, and 4-PR-2 respectively. Herbage mass in grazing exclosures was used to estimate aboveground production in 2012 and 2013. Trampling and harvest efficiency were estimated every other week in the MOB and each time cattle changed pastures in the 4-PR-1 and 4-PR-2 during 2010, 2011, and 2013. Aboveground production did not differ among treatments. Average daily gains of MOB were low (0.2 kg/head/day) compared to 4-PR-2 gains (0.8 kg/head/day). Low gains on the MOB pastures likely were related to high levels of trampling and poor forage quality late in the grazing season.

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Introduction

Throughout the 19th century, the majority of grasslands in North America were continuously stocked with a mixture of domesticated livestock. Many areas were public land open to grazing by anyone with cattle. By the early 1900s there had been a notable decline in grassland condition resulting in reduced herbage production, loss of wildlife habitat, increased soil erosion and a decline in species richness. Sampson (1913) reported on the benefits of an alternative grazing system, deferred rotation grazing. Sampson (1913) found that dividing a rangeland parcel into two pastures and deferring growing season grazing on one half of the parcel each year allowed depleted rangelands to recover from abusive grazing. Over the following decades researchers studied and developed grazing systems to increase production capacity, species richness, and wildlife habitat of North American grasslands. In the 1980s, a grazing method known as short duration grazing was introduced to North America by Goodloe (1969) which involved dividing land parcels into eight pastures or more and rotating livestock through the pastures two times or more each growing season. Originally developed by Allan Savory, this more intensive management resulted in higher grazing efficiency and capacity for many practitioners (Goodloe 1969, Savory and Parsons 1980, Savory 1983). The increased stocking density of this system is reportedly the factor leading to better grazing distribution resulting in greater grazing efficiency and capacity. Short duration grazing also allows forage plants a recovery period between grazing events to rebuild photosynthetic material and root energy reserves. Since its introduction, short duration grazing has been altered and intensified by producers until it has given rise to a method of grazing known as ultrahigh stocking density grazing or mob grazing.

Mob grazing involves concentrating grazing livestock into small paddocks to achieve stocking densities of 200,000 kg ha^{-1} or greater. Maintaining animals at these densities usually requires moving animals through multiple paddocks per day. In a mob grazing system each paddock is typically grazed only once per growing season. Practitioners suggest a wide variety of benefits from mob grazing including increased forage production, improved distribution of livestock grazing, and increased soil function and plant diversity (Gompert 2010; Peterson 2010).

The high stocking densities used in mob grazing systems is reported to result in even distribution of grazing, hoof action, and excreta across a pasture (Peterson 2014; Peterson and Gerrish 1994). Even distribution of grazing is said to reduce selective grazing by livestock. Selective grazing is considered detrimental by producers because undesirable plants are allowed to grow undisturbed while the most desirable plants are severely grazed placing them at a competitive disadvantage leading to eventual plant community dominance by less-desirable plant species. Increased grazing pressure and uniformity of grazing animal distribution eliminates this effect by forcing animals to graze the entire area of the pasture they are allotted. This reportedly results in increased utilization and increased harvest efficiency which can increase a pastures carrying capacity by 25 to 100% (Savory and Parsons 1980; Stuth et al 1981; Gompert 2010).

Even distribution of excreta is beneficial to the soil microbial community of a pasture. Nutrients in excreta are more readily available for use by the soil microbial community and become available to plants more rapidly than nutrients bound in plant material. Even distribution of excreta is considered by some to reduce the need for artificial fertilizers thus reducing production costs (Peterson and Gompert 1995).

Intensified hoof action is said to break up water repellant soil crusts and to incorporate plant litter, live plant material, and excreta into the soil increasing soil organic matter (SOM) inputs and nutrient cycle efficiency. It is also claimed that trampled vegetation covers and protects soil from erosion increasing soil hydrologic function, seedbed preparation and germination rates of grassland plants (Savory 1983; Savory 2013).

Practitioners who use mob grazing methods report increases in vegetation production of 100 to 300% as well as improved plant diversity which they believe to be a result of improved soil function and fertility, and even distribution of grazing pressure (Gompert 2010). The increase in vegetation production would allow for increased stocking rate resulting in increased animal production and greater profits for producers while maintaining the ecological integrity of the ecosystem. No quantitative research has ever been published on the effects of stocking densities common in mob grazing systems. Experimental evidence from less intensive grazing systems does not wholly support the claims associated with mob grazing. The following literature review is a brief summary of grazing systems effects on grassland ecosystems and animal production.

Grasslands

Grasslands can be defined as terrestrial ecosystems that are dominated by herbaceous vegetation, with or without shrub vegetation, maintained by fire, drought, grazing and/or temperature. Based on this definition researchers have estimated that between 31 and 43 % of the Earth's land area is grassland (White 2000).

Grasslands provide a variety of services including wildlife habitat, carbon (C) capture and storage, oxygen release, and animal products for human use. Grassland productivity depends on many factors. Climate, soil type, precipitation, evolutionary history and current disturbance regime all play a role in determining the productivity and species composition of any given grassland (Holechek et al. 1999). Climatic disturbances such as drought and flooding are largely beyond human control and disturbances such as fire can be only partially controlled through management. Large animal grazing is the disturbance that is most readily controlled by human management. Through controlling time, placement, and intensity of domestic livestock grazing, managers can have a significant impact on the vegetation production and species composition of grasslands (Vallentine 2001; Gerrish 2004)

Primary Production

Net primary production is defined as the total new vegetation production in a single growing season (Allen et al. 2011). Grassland vegetation production is determined by a number of factors including genetic production potential of the species present, availability of essential nutrients and water to those plants, and the health and condition of the plants.

Water and nitrogen (N) are the two soil nutrients that have the greatest impact on vegetation growth. Even though plants derive the vast majority of their C from the atmosphere, soil C content also plays a key role in soil nutrient cycling. In grasslands, primary production is divided into aboveground and belowground production. Perennial grasses alter allocation of resources above or belowground depending on current growing conditions (Dawson 2004). Above and belowground production often demonstrate dissimilar response to grazing treatments as a result of their impacts on growing conditions. The amount and type of primary production in a grassland system determines the goods and services that can be sustained through exploitation of the vegetation within that system.

Soil Quality

Soil quality has been defined as “the ability of the soil to function” (Larsen and Pierce 1991). The USDA further defines soil quality as “the ability of a specific soil to function for a specific use” (Mausbach 1996). In grasslands, soil quality is measured by the soils ability to provide structural support to vegetation, sustain biological diversity and productivity, store water and regulate water movement, and retain and cycle nutrients (Karlen et al. 1997). Because vegetation is frequently removed in grasslands, soil is of particular interest because re-growth of vegetation depends primarily on soil nutrient content and plant subsoil structures (Johnson and Matchett 2001).

Soil quality can be measured by physical and chemical properties (Doran 1994). Physical indicators of soil quality include texture, structure, strength, plant-available water capacity, and maximum rooting depth (Larson and Pierce 1991). A common measure of soil physical properties is bulk density. Bulk density is the ratio of mass to bulk (volume) of soil (Black and Hartgate 1986). Soils with lower relative bulk density tend to have greater soil structure, greater plant-available water capacity, and higher infiltration rates. Bulk density can change with management practices. Heavy grazing may cause compaction, reducing water holding capacity and infiltration while increasing bulk density (Vallentine 2001, Abdel-Magid el al. 1987). Chemical indicators of soil quality include nutrient availability and organic C among others (Larson and Pierce 1991). Nutrient availability is often measured as the Cation Exchange Capacity (CEC) which is affected by soil organic C. Cation exchange capacity is a measure of the number of positively charged ions that a soil can retain. These ions move into solution when soils are moist and become available for uptake by plants. Generally speaking soils with higher organic C content have higher CEC, and soils with higher CEC are more fertile (Brady and Weil, 2008).

Nutrient Retention and Cycling

There is a limited amount of any given nutrient on the face of the earth. Within grasslands, nutrients cycle between pools in the atmosphere, plant or animal tissue, and in the soil. The health and productivity of grassland ecosystems depends greatly on the rate at which they are able to cycle vital nutrients. Carbon and N are the most important nutrients for grassland health and productivity. While each of these nutrients cycle within their own pools, their cycles interact and in many cases are dependent on each other. In organic matter, N is chemically bound to C. The concentration of C relative to N will determine the rate at which the organic material can be decomposed and the nutrients become available for re-absorption and uptake by living plant material. The following sections provide a brief overview of each nutrient, its pools and cycles.

Carbon and SOM

The primary C pools are found as gas in the atmosphere and bound in organic material on the earth surface and in the soil. The Earth's soils constitute the largest pool of C, containing 30 to 50 x 10^{11} Mg C compared to the 7 x 10^{11} Mg contained in the atmosphere and the 4.8 x 10^{11} Mg in plant and animal biomass (Thomas and Askawa 1993, Stephenson and Cole 1999). Of the total C in the biosphere, more than 10% is contained in grasslands, with the largest pool being in the soil (Eswaran et al., 1993). Jobaggy and Jackson (2000) report approximately 22% of global soil organic carbon (SOC) is stored beneath grasslands.

Carbon is cycled from the atmosphere as CO_2 into living biomass through the process of photosynthesis. Once synthesized into organic C rings, it is used for growth, reproduction, and structural stability by the plant. Death of the plant, or root senescence in response to defoliation, deposits C bound in belowground biomass into the soil. Root tissue is the primary source of soil C. Aboveground biomass is deposited on the soil surface either as excreta after being grazed and processed by herbivores, or as dead vegetation that falls or is trampled to the soil surface. As soil organic matter is decomposed by soil microbes and fungi, readily available C is released to the atmosphere in the form of CO_2 gas as a product of respiration. Carbon structures that are not easily broken down become humus which is largely stable in the soil structure and is the primary fraction of soil organic matter.

Soil organic matter (SOM) is a small percentage of most soils but has a tremendous impact on soil function. There is two to three times more C bound in SOM than in living plants. Much of soils water holding capacity and cation exchange capacity are determined by SOM concentrations. Soil organic matter acts as a slow release nutrient source for live plants and is the primary source of energy and other nutrients for soil microbes which are essential to nutrient cycling.

Despite their smaller total C contents, animal and vegetation pools play a key role in the dynamics of SOC through excreta deposition and litter decomposition. Whether litter or excreta is the primary source of aboveground C depends on the severity of utilization of the grassland by grazers.

Nitrogen

Nitrogen is a critical component of all plants and living plant tissue. It is an essential element of all amino acids which form proteins, including the enzymes that control virtually every biological process; nucleic acids used for genetic code in DNA; and chlorophyll, where photosynthesis takes place.

Location of N pools are the same as those of C (atmosphere, soil, and organic material) but the pathways between these pools are quite different. While the atmosphere is 78% N_2 gas, this form of N is highly inert and not available for plants to use. Plants obtain most of their N from the soil in the form of nitrate. In grassland ecosystems without artificial fertilizer, new N soil input is primarily a result of N fixation by soil microbes. Nitrogen enters the soil through precipitation or wind, where it must be fixed by living organisms, or return to the atmosphere. Nitrogen is fixed by the soil microbial community including, free-living bacteria, rhizobium symbiosis, symbiotic cyanobacteria, actinomycete, rhizocoenoses, and nodule symbiosis (Haynes 1986a).

Other soil N is supplied through the re-deposition of biological tissue containing N. At least 95% of soil N is bound in organic compounds and essentially unavailable for plant use in most systems. Through mineralization, soil microbes excrete enzymes that digest N containing compounds such as amino acids and release NH_4^+ which then undergoes the process of oxidation to become nitrate which is available for plant uptake (Plate 1980). Annual mineralization rates are typically between 1.5 and 3.5% of soil N content. The rate at which N is mineralized interacts with soil chemistry to determine the amount available for use by vegetation and can have a major effect on the productivity of a grassland.

Some forms of N can be absorbed through the leaves of the plant by simple diffusion through the stomata and then into intercellular air spaces of the leaf. This process is known as foliar uptake and primarily involves N in the form of urea and ammonia (Haynes 1986b; Denmead et al., 1976). While it has been shown that plants have the capacity to absorb N through foliar uptake, the importance of this process to grasslands remains largely unknown (Coyne et al., 1995).

Grazing Management

Grazing management is the practice of manipulating the grazing animal-forage plant-soil complex (Vallentine 2001). The purpose of grazing management is to develop a plan that directs land use to achieve optimum sustainable returns that meet management objectives (Vallentine 2001.) Proper grazing management minimizes livestock production costs, mitigates soil erosion, and often results in increased vegetation production while poor grazing management can decrease grassland persistence and result in grassland degradation (Garay et al. 2004; Franzluebbers et al. 2000; Newman and Sollenberger, 2005; Wright et al. 2004).

Grazing management can be quantified in terms of frequency, intensity, and timing in relation to plant growth stage and environmental conditions, and is usually accomplished through the use of grazing systems. Grazing systems are designed to improve grassland health and function thus increasing forage production for livestock, harvest efficiency, and animal production, while improving wildlife habitat and increasing nutrient cycling and retention (Briske et al. 2008; Heitschmidt and Walker 1983; Holechek et al. 2004). Grazing management is one of several tools available to land managers to manipulate ecosystem processes.

Grazing Frequency

Grazing frequency refers to the number of times a plant or pasture is defoliated in a growing season and the recovery period between defoliation events. Reece et al. (1996) concluded that an increased grazing frequency allowing less than 60 days rest between defoliation events decreased total organic reserves of sand bluestem (*Andropogon hallii*) and prairie sandreed (*Calamovilfa longifolia*). They also concluded that periodic deferment until August or later is needed to maintain high reserves in both species.

Research simulating grazing on subirrigated meadows in the Nebraska Sandhills indicated that an increase from 2 to 5 defoliation events in a growing season significantly reduced root mass production of slender wheatgrass (*Elymus trachycaulus*) but did not affect aboveground production (Volesky 2011). Similarly, Gillen et al. (1991) found that increasing rotation speed by decreasing the duration and increasing the frequency of grazing events produced no significant changes in plant community productivity or species composition in Oklahoma tall-grass prairie.

Grazing Intensity

Grazing intensity is the amount of aboveground biomass from the current year's production of an individual plant that is grazed or utilized by livestock (Heady and Child 1994). It is most commonly described in terms of grazing pressure (animal demand per unit of available forage), stocking rate (animal demand per unit of land area over time), or stocking density (live animal demand per unit land area at a point in time). Generally, it is a measure of grazing severity in relation to a plant, species, or plant community (Sollenberger and Newman 2007, Vallentine 2001). The level of grazing intensity a plant experiences has a tremendous impact on its productivity, quality, persistence, and the long-term sustainability of grazed lands (Waller and Sale 2001, Newman and Sollenberger 2005, Biondini et al. 1998). Grazing intensity also has an impact on soil quality and function as well as animal performance (Baron et al. 2002, Ingram et al. 2008, Newman et al. 2002). Because of this, appropriately regulating grazing intensity is considered the most important grazing management practice. The results of using grazing intensities greater than those sustainable for a grassland results in both long-term and short-term declines in vegetation production (Heitschmidt and Stuth 1991, Houston and Woodward 1966, Vallentine 2001).

In livestock production systems, grazing intensity and forage utilization is commonly measured by animal units. One animal unit (AU) is a 455 kg cow with or without a calf up to 6 months old (The Society of Range Management 1989). Animal demand can be calculated in AUs by dividing the total live animal weight by one AU (e.g., 10 steers @ 300 kg steer^{-1} = 3000 kg / 455 kg AU^{-1} = 6.6AU). AUs are often modified with units of time. The forage required to sustain one AU for one month is referred to as an AUM; for one day is an AUD; for one year is an AUY.

Grazing pressure

Grazing pressure describes the animal unit demand per unit of forage. It can be calculated as either instantaneous grazing pressure, or cumulative grazing pressure. Cumulative grazing pressure is the animal unit demand per unit forage over a period of time and is the primary factor determining how severely and how often a plant is grazed. Instantaneous grazing pressure is the animal demand unit per unit forage at an instant in time and has a significant impact on grazing distribution. Continuous and short duration grazing systems may have similar cumulative grazing pressures, but will have very different instantaneous grazing pressure. For example, if 20 steers are grazed on 100 ha for one growing season, the cumulative grazing pressure will be equal regardless of grazing system. If that 100 ha is divided into 9 equal paddocks, and steers are rotated through the paddocks once during the growing season, instantaneous grazing pressure will be nine times greater upon entering a paddock than if the pasture was continuously grazed. The same number of animal units are grazing one-ninth of the forage, increasing the AU demand per unit forage nine fold. The increased instantaneous grazing pressure in the nine smaller pastures will reduce the steers' ability to selectively graze and increase grazing distribution.

Stocking Rate

Stocking rate describes the animal to land relationship over time and is usually expressed as an amount of forage available or utilized per unit land area over a period of time. (e.g., 2 AUM ha^{-1}, 500 kg ha^{-1} $year^{-1}$). Stocking rate is a critical management decision in managing grazing animals on grasslands. Carrying capacity is the maximum number of animals that can be continuously supported on a given area of land without damaging grassland resources (e.g. vegetation, soil, wildlife). Land managers may choose to utilize stocking rate higher, equal to, or lower than carrying capacity depending on management objectives. Before such decisions are made the consequences should be considered. Consistently stocking above carrying capacity results in rangeland degradation. Rangeland degradation may result in reduced plant productivity, reduced soil function and increased erosion, lower livestock gains, and loss of wildlife habitat (Ralphes et al. 1990, Heitschmidt and Walker 1996, Holechek et al. 1998). Classels et al. (1995) found that end of season standing crop decreased as stocking rate increased in both rotational and continuously grazed pastures leaving soil exposed to greater erosion and potentially reducing plant vigor. Understocking results in lost economic returns and in some areas, a reduction of vegetative productivity through excessive biomass accumulation on the soil surface. This buildup is indicative of a poorly functioning mineral cycle and reduced soil fertility (Knapp and Seastedt 1986). In many cases such buildup can be broken down and returned to contact with the soil through well managed animal impact.

Stocking Density

In reference to livestock grazing, stocking density is defined as the animal demand per unit of land area at an instant in time (Allen et al. 2011). It is important to note that while stocking density and stocking rate are related to one another they operate independently. Stocking rate can be held constant while stocking density changes so long as there are accompanying changes in grazing period length. A 100 ha pasture grazed by 100 steers for 100 days has the same stocking rate as 100 ha grazed by 10,000 steers for one day or 1000 steers for 10 days with stocking density varying greatly as number of steers and grazing period lengths change (Vallentine 2001).

More intensively managed grazing systems are typically correlated with higher stocking densities. Increased stocking density coupled with decreased grazing period length has been widely acclaimed as a tool to increase harvest efficiency and greatly improve rangeland productivity and is the foundational theory behind ultrahigh stocking density grazing (Savory 1980, Gompert 2010).

Management Intensity

Differentiating between grazing intensity as defined above and management intensity of a grazing system is important. Management intensity, or system intensity, refers to management and labor inputs of a grazing system. This includes, among other things, the effort and time required to plan, enact, direct, and monitor the effects of a grazing system. Generally, grazing systems involving multiple pastures or paddocks per herd are considered more management intensive whereas systems with fewer than 7 or 8 pastures per herd are considered less intensive. Management system intensity is directly correlated with the amount of time and labor a manager invests in maintaining the system.

Timing

Timing of grazing, specifically the relationship between environmental conditions and timing of grazing, can have a significant impact on plants and plant communities. The survival of perennial plants requires that they enter the dormant season with sufficient carbohydrate reserves to maintain a rate of metabolic cellular respiration sufficient to keep meristem tissue from freezing during the winter, initiate growth in spring, and produce new photosynthetic material following a defoliation event. Plants must be able to take advantage of favorable growing conditions when temperature, moisture, and nutrients are available. One primary focus of grazing management is to control timing of grazing and provide recovery periods for plants to build reserves while environmental conditions are favorable, i.e. water and nutrients are readily available and soil and air temperatures are adequate. (Waller et al. 1986). Because plants can recover most rapidly under optimum environmental conditions, defoliation events early in the growing season between emergence and peak growth followed by long recovery periods are generally considered to be less detrimental to a plant than defoliation events during later growth periods (Holechek 2004; Vallentine 2001). To ensure survival through the dormant season perennial grasses translocate carbohydrates from photosynthetic material to their roots after tillering is complete. Grazing early followed by recovery allows the plant to tiller and store root reserves undisrupted and helps ensure its survival (Reece et al. 2007).

Grazing Systems

History

In the early 20th century, North American rangeland managers began to develop grazing systems in an effort to restore grassland that had become degraded through decades of severe overgrazing in the late 19th century (Briske et al. 2008 Holechek et al. 2004, Heady 1999). Prior to the 20th century, the grasslands of North America were mostly continuously stocked and much of it was public property open to use by anyone with livestock (Klipple and Costello 1960). Formal research of grazing and rangelands did not begin until after 1900 (Lodge 1970). Grazing systems were first introduced in 1913 when Arthur Sampson published his findings that using grazing systems could be helpful in restoring depleted grasslands (Sampson 1913). In the century that has followed, grassland managers have developed grazing systems of ever increasing management intensities in an effort to improve grassland health and productivity.

Continuous Grazing

Continuous grazing is a method of grazing wherein animals graze the same unit of grassland for the entire year or for the entire growing season with no periods of non-grazing (Holechek et al. 2004). Some consider continuous grazing to be synonymous with poor range condition but poor range condition is more likely a result of inappropriate stocking rate than continuous grazing (Vallentine 2001).

Deferred and Rest-Rotations

Sampson (1913) found that dividing a rangeland parcel into two pastures and deferring growing season grazing on one-half of the parcel each year allowed rangelands to recover and resulted in significant improvement of depleted rangelands. Deferred rotation systems typically consist of 2 to 5 pastures with one pasture deferred from grazing each growing season. Rest rotation systems consist of 3 to 5 pastures with one pasture rested annually for a complete calendar year. Rotation of livestock through pastures and a single occupation per year are landmarks of these grazing systems. The periodic deferment or rest of each pasture provides vegetation with uninterrupted reproduction and storage efforts and is reported to significantly improve range condition (Owensby 1973; Sampson 1951; Stoddard et al. 1975). While some studies showed little or no difference in deferred grazing and continuous grazing systems in terms of primary production and animal performance (Thompson 1938; Hargrave 1947) others showed significant increases in cattle weight gains in deferred rotation systems (Sarvis 1923; Black 1937). These types of grazing systems became widely accepted by the 1930s and widely used through the 1960s; they are still used in many areas today (Vallentine 2001). Sampson (1913) and other early scientists in range management developed the foundational system of management that focuses on the use of grazing systems and strategies to improve rangeland condition and productivity.

Short Duration and Management-Intensive Grazing

Short duration grazing (SDG) was developed by Allen Savory (Savory 1983) in Zimbabwe Africa. It was originally introduced to the USA by Sid Goodloe in 1969 and then by Savory (Goodloe 1969; Savory and Parsons 1980; Savory 1983). This method received a great deal of attention as it was reported to significantly improve range condition and productivity under higher stocking rates while maintaining or improving animal performance (Savory and Parsons 1980; Savory 1983). Short duration grazing is accomplished by dividing rangeland parcels into no less than 8 paddocks. Grazing animals are rotated rapidly through the paddocks multiple times each growing season with each occupation lasting no more than 14 days (Manley 1997; Savory and Butterfield 1999). This grazing method results in short, intense periods of animal impact followed by relatively long periods of rest and was designed to mimic the natural movement of large ungulate herds under which grasslands evolved. This grazing system is designed to increase stocking rate by improving grazing distribution and harvest efficiency and improving diet quality for grazing animals. Recovery periods are the primary focus of this system. In theory, proper management allows key forage species to recover between grazing periods and then be re-grazed before reaching reproductive growth stage. This maintains a high quality diet for livestock without detrimentally effecting key forage species. (Savory 1983; Savory and Parsons 1980).

Since its introduction, short duration grazing has been adapted and adjusted by land managers which has led to several similar, intensified grazing systems. Management-intensive grazing (MIG) was introduced by Gerrish (2004) and involves very small grazing paddocks requiring that grazing animals be moved every 2 or 3 days. Paddocks are grazed multiple times throughout the growing season, with the goal of maintaining forage plants in their vegetative stage. This method of grazing was designed to increase absorption of solar radiation by the landscape. Grassland plants absorb more solar energy in their vegetative stage than in their elongation or reproductive stage (Gerrish 2004). Grazing pastures rapidly, allowing regrowth to occur, and then re-grazing prior to forage plants reaching reproductive stage, is said to increase total energy absorbed across the landscape which would equate to higher overall productivity (Gerrish 2004).

Ultrahigh Stocking Density Grazing

Ultrahigh stocking density grazing, or mob grazing, is the practice of restricting grazing animals to very small paddocks in order to achieve stock densities (stock density = live animal weight/land area) from 200,000 ka ha^{-1} to as high as 1,000,000 kg ha^{-1} or greater. This is usually done through the use of portable electric fencing creating very small paddocks and moving grazing animals multiple times each day. Practitioners of mob grazing claim a variety of benefits such as, increased forage production, increased stocking rates, improved harvest efficiency, higher animal production per unit land area, and an increase in native species abundance. These benefits are largely attributed to the effects of mob grazing on soil nutrient cycling and the elimination of selective grazing (Peterson 2010, 2014; Gompert 2010). Concentrating animals on a small area is said to increase nutrient cycling by evenly distributing excreta and through a relatively high percent of vegetation trampling. This increases soil organic matter and nutrient content resulting in more fertile soils (Peterson and Gerrish 1995). The validity of these claims has never been quantified and supported in the literature.

Effects of Stocking Density

Effects of the stock densities used in mob grazing systems have never been quantified. Studies comparing other grazing systems are plentiful, and while few if any of these studies have quantified stocking densities, examining the effects of intensifying grazing systems may lend insight to the claimed benefits of mob grazing. Increases in management intensity of grazing systems are typically correlated with an increase in stocking density. If there is no change in stocking rate, intensifying a grazing system through the use of more, smaller pastures per herd, inherently increases stocking density.

Grazing Distribution and Harvest Efficiency

Sub-dividing pastures has long been accepted as a method of increasing uniformity of utilization (Hart et, al. 1993). Norton (1994) hypothesized that smaller paddocks and higher stocking densities increases forage available to grazing animals because they encounter forage in all areas of the pasture. The findings of Barnes et al (2008) support this hypothesis. Barnes et al. (2008) found that smaller paddocks and intensified grazing rotation increased grazing distribution and uniformity of pasture use compared to continuous grazing. Once a rotational system has been established, the effect of different intensities may not have as large an effect. Burboa-Cabrera et al. (2003) found that differing stocking densities within four pasture rotations between 9, 18, 27 and 54 steers ha^{-1} did not affect grazing distribution in warm-season grass pastures in Nebraska.

Increasing grazing distribution uniformity is said to increase harvest efficiency. Harvest efficiency can be defined as the amount or proportion of available forage that is consumed by grazing animals. Increasing harvest efficiency is a point of focus for livestock producers as animal production is directly correlated with both the quality and quantity of forage harvested from grassland. Increasing harvest efficiency would allow producers to increase animal production per unit land area. The prime objective of increasing grazing distribution as discussed above, is that it result in enhanced forage utilization which, if realized, has been reported to increase carrying capacity as much as 25 to 100% (Savory and Parsons 1980; Stuth et al 1981). Garrish and Morrow (1999) reported a moving livestock every 3 days in a MIG system increased harvest efficiency to 68%. On the other hand, in Texas, an increase in rotation intensity from a 14 pasture rotation to a 42 pasture rotation did not result in any increase in harvest efficiency at like stocking rates (Heitschmidt et al. 1987a).

Research has also shown that decreasing paddock size and increasing stocking density results in more uniform distribution of excrement across a pasture (Morton & Baird 1990; Peterson & Gerrish 1995).

Utilization and Trampling

Utilization is the total vegetation that is consumed, trampled, or fouled by grazing animals and is typically presented as a percentage of total vegetative biomass production. Research has shown that utilization is more closely tied with stocking rate than stocking density. Hart et al. (1998) found that trampling increased as stocking rates increased but no differences were found in utilization between continuous, deferred, and short duration grazing systems within stocking rates. Hart et al. (1993) also found that distance from water was a key factor in utilization. They found that utilization was significantly lower 3 km from water than at any point in adjacent small pastures regardless of grazing system in continuous and rotational pastures.

Trampling (hoof action) is the effect of grazing animals stepping on vegetation and soil in grazing areas. Increasing stocking density has been reported to increase hoof action and provide many beneficial results to grassland ecosystems (Savory 1983; 2013). Knapp and Seastedt (1986) found that the accumulation of detritus on the soil surface and of standing dead vegetation significantly affected the productivity and species composition of the tall-grass prairie. Detritus accumulation is indicative of a poorly functioning nutrient cycle which usually results in limitation of plant production. Hoof action is a tool to break up detritus accumulation and incorporate it into the soil. Litter in contact with the soil is said to stabilize and protect the soil surface and increase infiltration (Savory 1980; 2013). Again, research does not fully support these claims.

In a greenhouse simulation experiment, Abdel-Magid et al. (1987) found that severe trampling increased soil bulk density 3% and decreased infiltration by 57%. However, results were less severe when the same level of trampling took place over a 4 day period compared to a 32-day period. Warren et al. (1986; 1986a; 1986b) measured infiltration and runoff of intensive rotational pastures and found that increasing stocking density did not improve infiltration or reduce runoff or sediment transport. They determined that rest is more important that density for hydrologic stability in soils and that little if any benefit could be expected from increasing numbers of small pastures. Balph and Malecheck (1985) found that trampling is also effected by vegetation. In crested wheatgrass pastures, increasing stocking density was ineffective at trampling standing herbage because animals avoid stepping on tussock and bunch-type grasses. Dormaar et al. (1989) found that hoof action was ineffective at incorporating plant material into the soil in fescue grass pastures.

Winkel et al. (1991) found that trampling was effective at incorporating grass seeds into soil. He found that heavy trampling buried 45% of seeds of four species of grass whereas no trampling or light trampling buried only 20 and 28% of seed respectively. Regardless of trampling effects on seed incorporation, there is question about its importance. Salihi and Norton (1987) found that nearly all crested wheatgrass seedlings in a 10-pasture intensive-rotation grazing system were trampled (and likely killed).

Nutrient Cycling

Carbon

Grazing management practices can affect C pool size and cycling rates in grasslands by altering microclimate and light, water, and nutrient availability, as well as affecting the proportion of C allocated to above or belowground biomass (Frank and Groffman 1998; Hobbs 1996; Hobbie 1992; Ingram et al. 2008). Derner et al. (1997, 2006) found grazing increased soil C in short-grass steppe and short-grass prairie had no effect on soil C in tall-grass prairie when compared with un-grazed areas. Walters and Martin (2003) on the other hand found that grazed areas of the tall-grass prairie did have higher SOM than un-grazed areas. Reeder and Schuman (2002) found similar trends in both short-grass steppe and mixed-grass prairies. Grazed for 56 and 12 years respectively, both short-grass and mid-grass prairie contained higher SOM than un-grazed areas. It has also been shown that grazed areas of the tall-grass prairie produce less C flux than un-grazed areas (Johnson and Matchett 2001). In the southeastern U.S., Franzluebbers (2005) reported the rate of soil C accumulation in grazed pastures to be 1.4 Mg ha^{-1} yr^{-1} while un-grazed pastures accumulation was less than half that. The cause of this relatively consistent response to grazing is thought to be the result of root material die off as well as aboveground biomass deposition and incorporation in the form of excreta and litter during grazing events (Reeder and Schuman 2002; Franzluebbers et al. 2003; Conant et al. 2001).

Soil C content also responds to grazing intensity. Reeder and Schuman (2002) found that soil C was highest under the most heavily stocked grazing systems in both mixed-grass and short-grass rangelands of the Great Plains. Comparing three stocking rates grazing yaks on the Tibetan plateau, SOC responded positively to stocking density with soil C of 9800 g m^{-1}, 10,160 g m^{-1}, and 11,730 g m^{-1} of C in the top 30 cm of soil of the light, moderate, and heavy stocking rates respectively (Gao et al. 2007).

Aboveground C on the other hand, decreases as grazing intensity increases. In an examination of plant-soil C ratio, Schuman et al. (1999) found that total aboveground C decreased linearly as stocking rate increased. Non-grazed, lightly-stocked and heavily-stocked treatments contained aboveground C totaling 1620, 1280, and 750 kg ha^{-1} respectively.

Nitrogen

Research has shown that grazing management and systems do effect N cycling in grasslands throughout a variety of climates and grassland types. Patra et al. (2005) found that grazing had a significant positive impact on the populations and function of soil microbes responsible for N mineralization. In Yellowstone national park results showed that average net N mineralization was twice as high in grazed areas compared to fenced exclosures (Frank et al. 1998). Similarly, Walters and Martin (2003) found that grazed areas of the Kansas tall-grass prairie contained higher levels of soil N and phosphorus than adjacent, un-grazed areas. Johnson and Matchett (2001) found that increases in soil N resulting from grazing lead to an increase in N:C ratio in tallgrass root material increasing root decomposability, which would contribute to accelerated N cycling.

Baron et al. (2000) found that increasing grazing intensity increased the rate of N cycling through the soil-plant-animal system due to the increased deposition of animal excreta. N contained in excreta is a form more readily available to microbes than that found in plant material. Shifting surface litter composition to a higher proportion of animal excreta and a lower proportion of undigested plant material changes litter quality and increases N cycling rate (Haynes and Williams, 1993; Hobbs 1996; Hatch et al. 2000).

Primary Production

Aboveground

Increased herbage production is one of the most common claims surrounding mob grazing. Some practitioners claim to have doubled or tripled their aboveground production as a direct result of mob grazing (Gompert 2010). Research has shown that moderate grazing increases productivity of grasslands compared to non-grazed grasslands (Patton et al. 2007) but quantitative research at stocking densities used in mob grazing systems is essentially non-existent. Research conducted on the effects of grazing at lower densities among varied grazing systems has produced varied results, not all of which support the purported benefits of mob grazing.

As mentioned previously, research has shown a significant advantage to deferred rotational systems compared to continuous grazing. In a 16 year study in the Kansas tall-grass prairie, Owensby et al. (1973) found that deferred rotation grazing showed higher annual production and standing crop than continuously grazed pastures at the same stocking rate.

Research on the effects of rotational grazing has been mixed. Gillen et al. (1998) found that while rotational grazing did result in higher end of season standing crop than continuous grazing, this produced no significant change in standing crop or species composition over the duration of the study. They did suggest that over time, this higher standing crop could lead to increased rangeland health but they were not able to observe these changes within their study. Annual net primary production was not affected by the increase in stocking density associated with a 42 pasture rotation compared to a 14 pasture rotation after 4 years (Heitschmidt et al. 1987b).

A more recent study conducted in the Texas tall-grass prairie compared vegetative and soil characteristics between ranches that had been managed under different grazing systems, for at least a decade. Researchers found that multi-paddock rotational grazing had higher aboveground primary production and higher end of season standing crop than continuous grazing treatments at the same stocking rate. (Teague et al. 2011).

In a synthesis paper examining the results of 23 studies on grazing systems and their effect of primary production, Briske et al., (2008) reported that in 87% of the studies they examined, continuous grazing system plant production was equal to or greater than that in rotational grazing systems. In an earlier review of 15 studies conducted in North America, Holeckek et al. (1999) reported an average 7% increase in herbage production in rotational systems compared to continuous grazing. They also reported that precipitation gradient was an interacting variable among studies reviewed; while there was little or no difference in production in arid climates, grasslands under specialized grazing systems in humid regions saw an average increase in herbage production of 20 to 30%.

Volesky et al. (2004) found that stocking rate had a greater effect on subirrigated Sandhills meadow productivity than grazing system. Increasing stocking rate above 148 AUD ha^{-1} resulted in a linear decline in total vegetation production but increasing grazing frequency from 3 to 5 times per growing season had no effect.

Belowground

Research on roots and root response at differing stocking densities is limited at best. It is known that perennial grasses have the ability to alter their root structure in response to grazing events (Dawson 2004). In sub-humid pastures of Wisconsin, it was found that both continuous and short duration grazing decreased root production in the top 15 cm of soil in cool-season pasture (Oates et al. 2011). On wet meadow in the

Nebraska Sandhills, increasing frequency of defoliation from twice to five times per growing season, as might happen in SDG or MIG systems, decreased total root biomass production of slender wheatgrass but did not affect net aboveground production. The same treatments did not affect the root mass of Nebraska Sedge or Birdsfoot trefoil on the same meadow (Volesky et al. 2011). Johnson and Matchett (2001) also observed a reduction in root growth in grazed areas of the tall-grass prairie, and hypothesized that it was the result of increased soil N availability which decreased the required C allocation to roots.

Derner et al. (2006) found that grazing effected not only root production but also the type of roots produced. In comparing grazed to non-grazed plots at three sites across climatic gradient, they found that grazed grasses increased the relative biomass of fine root production across all soil depths in short, mid, and tall-grass prairies.

Species composition

Most of the world's grasslands and the species that inhabit them evolved under some form of grazing pressure. Grazing has been shown many times to increase or at least maintain species diversity on rangeland (Walters & Martin 2003, Collins et al. 1998) but the results of different grazing systems and their effects are varied. Research has shown that continuous grazing tends to increase species diversity when compare with non-grazed grasslands. In the Kansas tall-grass prairie, Towne et al. (2005) found that continuous grazed pastures increased in species richness at both small and large spatial scales (10 m^2 and 200m^2) in pastures grazed by both cattle and bison compared to non-grazed exclosures.

Research on the effects of different grazing systems on species composition has been mixed at best. Researchers in Texas studied ranches that had been managed under either continuous grazing or rotational grazing systems for at least nine years. Research showed that rotational grazing systems had more desired warm-season tall-grass species as a percent of production and in kg ha^{-1} than continuous grazed systems at the same stocking rate. Continuous grazed systems had a higher percent composition of less productive short-grass species and annual forbs than rotational systems at comparable stocking rates (Teague et al. 2011). On the other hand, researchers in Oklahoma saw no positive impacts on species composition in rotational versus continuous grazing treatments (Gillen et al. 1998). In a study conducted in Argentina, rotational grazing did not change species abundance compared to continuous but did promote a higher relative composition of more desirable and palatable forages (Jacobo et al. 2006).

While research results vary, in general research supports the theory that stocking rate has the greatest effect on species composition rather than grazing systems and their associated stocking densities. Many studies have been conducted showing changes in species composition in response to varied stocking rates (Hart & Ashby 1998, Ownesby et al. 1988, Gillen et al. 1998, Hickman et al. 2004).

Reece (1986) suggests that shifts in species composition resulting from grazing management practices may not be visible for many years. Some researches argue that the results of gradually intensifying systems over the past century are becoming evident in the Great Plains and are not entirely favorable. One of the primary reasons producers adopt a rotational grazing system is in hopes of achieving more uniform utilization of their pastures. While it has been shown that dividing and sub-dividing pastures increases pasture utilization and decreases selective grazing, some argue that the costs of such systems far outweigh the benefits from an ecological standpoint. As grazing systems become more intensively managed and pastures more uniformly grazed, species which require extreme grazing or little to no grazing are selected against and species which best tolerate a moderate level of grazing are favorably affected. Managers tend to select grazing practices which favor the forage plants they believe to be of the greatest benefit to their livestock and evaluate the health of their rangelands based on the presence and abundance of these key species. As these practices have taken hold and grazing systems have intensified, a significant loss of wildlife habitat and species richness has occurred. This loss of diversity leads to a decrease in the overall stability of grassland ecosystems and the ability of the system to adapt and produce during extreme disturbance events. There has been a recent push for the restoration of grazing practices that allow for uneven use of rangelands in an effort to restore spatial structural heterogeneity to the rangelands of the Great Plains (Fuhlendorf 2001, Briske et al. 2003, Briske et al. 2008).

Animal performance

As with most topics addressed thus far, animal performance in mob grazing systems has not been largely quantified. However, research among other grazing systems has shown either no response to grazing system or a negative response to increased system intensity. Response to stocking rate has also been mixed.

Cattle performance is expected to increase in SDG and MIG systems as animals are regularly presented with fresh, high quality forage (Kothmann 2009). While Oates et al. (2011) reported that SDG increased forage availability and quality compared to continuous grazing, their study only simulated SDG systems and could not yield quantitative results for animal performance in either system. In Oklahoma, McCollum et al. (1999) reported a significant decrease in ADG per head in short duration grazing system compared to continuous grazing at like stocking rates. They hypothesized that this decrease in animal performance may have been a result of decreased intake in the SDG system, but offered no explanation for why intake decreased. Hart et al. (1993) found that pasture size effected animal gains more than grazing system. Animals in large continuous pasture yielded lower gains than those in small pastures, but there was no difference in gains between animals in small continuous and small rotational pastures. They hypothesized that distance traveled between feed and water each day affected gains rather than grazing system.

Volesky et al. (1990) found that intensified rotational grazing did allow for a slightly higher stocking rate, but the benefits of increased stocking rate were largely lost to a decrease in animal performance. In a 2008 review of over 30 grazing studies, Briske et al. (2008) found that continuous grazing systems produced equal or greater animal gains per individual and per unit land area in 92 and 84% of studies reviewed respectively.

Animal performance is generally expected to decrease as stocking rate increases beyond a certain threshold. This was found to be the case by Hart et al. (1988) who found that ADG in yearling steers decreased as grazing pressure increased beyond 29 steer days ton^{-1} of forage. A 55 year study in west Kansas short-grass prairie showed heifer gains decreased linearly as stocking rate increased (Hart and Ashby 1998). In Oklahoma, increasing stocking rate decreased individual animal performance but increased total gain per unit land area (McCollum 1999). Conversely, Owensby et al. (1988) found that increasing above recommended stocking rate in the Kansas Flinthills did not affect individual animal gains which resulted in significantly higher animal gains per unit land area.

Sub-irrigated Sandhills Meadows

One of the largest grassland regions in the Great Plains is the Sandhills region of Nebraska and South Dakota; it is the largest contiguous dune field in the western hemisphere and one of the largest vegetation stabilized dune fields in the world (Bleed and Flowerday 1990). Of the 4.5 million ha of Sandhills in Nebraska, approximately 10% is wet or sub-irrigated meadows scattered throughout the region in wide flat valleys between elevated dune formations (Rundquist 1983). These sub-irrigated meadows are the result of high rainfall infiltration rates through the sandy soils of the surrounding uplands as well as former streams that have been blocked by historic dune mobilization (Loope and Swinehart 2000). Stream blockage has raised the water table as much as 25 m in some areas of the Sandhills (Loope 1995). This high water table has resulted in the establishment of sub-irrigated meadows that provide well watered, lush, highly productive ecosystems in an otherwise semi-arid environment (Bleed and Flowerday 1990).

Because the soils of the Sandhills are highly erodible when vegetative cover is removed, the area is not considered suitable for traditional tillage farming and is used primarily for beef cattle production. Historically (since settlement by Euro-Americans), the meadows have been used primarily as a source of hay for livestock winter feed. Typically hayed in early to mid-July, meadows would be grazed only during the dormant season, removing regrowth that occurred after haying (Coady and Clark 1993). Sandhills meadows were originally dominated by warm-season grasses common to the tall-grass prairie, but most are now dominated by introduced cool-season grasses and legumes as well as native sedges and rushes (Bleed and Flowerday 1998; Ehlers 1952).

Over the past couple decades there has been a growing interest and increased research in grazing Sandhills meadows (Adams et al. 1994; Horney et al. 1996). Removing forage with livestock rather than machinery can extend the grazing season and reduce costs for producers (Adams et al. 1994). Early spring grazing on meadows, when forage quality and the nutritional demands of lactating cows are both high, has resulted in increased cow body condition and calf weight gain (Adams et al. 1994; Horney et al. 1996). Early season grazing has also been shown to delay forage maturity resulting in higher quality hay harvest later in the summer when water tables have declined slightly making meadow hay more accessible for harvest (Volesky et al. 2002).

Producers who use mob grazing in the Sandhills region of Nebraska typically do so on sub-irrigated meadows. The high production potential allows ultrahigh stocking densities to be achieved with a reasonable number of moves each day. Ample water availability aids in rapid recovery and regrowth of vegetation. Previous research has shown these ecosystems to be highly productive and resilient (Volesky et al. 2011; 2004; Volesky and Schacht 2010).

Conclusion

There has been essentially no replicated research published on the effects of ultrahigh stocking density (mob) grazing on vegetation production, soil function, species composition, grazing distribution, and animal performance. Anecdotal evidence and producer testimonies of the advantages of mob grazing abound, and there is a growing interest in mob grazing among producers. Research on the effects of stocking density and grazing rotation at lower stocking densities has produced mixed results and does not wholly support the claims made about mob grazing.

Vegetation production and species diversity have shown significant response to stocking rate but shows little or no response to intensive grazing systems (Cassels et al. 1995; Hart et al. 1998; Manley 1997, Gillen 1998; 1991; Heitschmidt et al. 1987b; Hart & Ashby 1998; Ownesby et al. 1988; Gillen et al. 1998; Hickman et al. 2004). Reece (1986) suggests that shifts in plant communities may require extended periods of time to manifest themselves. This would limit much of academic research's ability to detect such changes as most experiments last only a few years.

Decreased pasture size and distance from water affects grazing distribution regardless of grazing system (Hart 1993; 1998) while increasing rotation intensities does not appear to have a significant effect (Heitschmidt et al. 1987a; Burboa-Cabrera et al. 2003).

Grazing has been shown to impact nutrient cycling with higher grazing intensities favoring the deposition of excreta over plant tissue. Excreta are more readily decomposed and increases nutrient cycling (Frank and Groffman 1998; Hobbs 1996;

Hobbie 1992; Ingram et al. 2008; Reeder and Schuman 2002; Haynes and Williams, 1993; Hatch et al. 2000). If mob grazing significantly improves evenness of excreta deposition across a pasture it could prove beneficial to soil nutrient cycling.

Soil hydrologic function has shown negative response to stocking density with extended rest being more important for soil hydrologic function than stocking density. However, long rest and short impact result in lower soil bulk density and better hydrologic function than extended low intensity impact (Warren et al. 1986; Abdel-Magid 1987).

Animal performance has been shown to decrease as stocking density increases (Briske et al. 2008; McCollum et al. 1999). Practitioners claim increased stocking rates lead to increased animal gain per unit land area, but this has not been shown in literature.

While research may not fully support the outcomes of mob grazing, producers who employ the practice continue to report benefits (Gompert 2010, Peterson 2010, 2014 Savory and Butterfield 1999, Savory 1983). None of the research involving stocking densities has involved densities approaching those used in mob grazing systems. Conducting replicated, quantifiable research on the effect of ultrahigh stocking densities on vegetation production, species diversity, harvest efficiency, and animal performance will provide information for interested producers and the first publishable research in this field and hopefully lay the foundation for future research in mob grazing and its' most applicable uses.

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Chapter 2:

Grazing System Effects on Forage Production, Utilization, and Botanical Composition of Nebraska Sandhills Meadow

Introduction

Ultrahigh stocking density grazing or mob grazing, involves concentrating grazing livestock into small paddocks to achieve stocking densities of 200,000 kg ha^{-1} or greater. Maintaining animals at these densities usually requires moving animals through multiple paddocks per day. In a mob grazing system each paddock is typically grazed only once per growing season. Practitioners report a wide variety of benefits including increased forage production, increased plant diversity, improved distribution of livestock grazing, improved soil function and rapid rate of soil development (Gompert 2010; Peterson 2010). The ultrahigh stocking densities used in mob grazing systems reportedly result in even distribution of grazing pressure, hoof action, and excreta across a pasture (Peterson 2014; Peterson and Gerrish 1995).

Even distribution of grazing pressure is said to eliminate selective grazing by livestock. Selective grazing is considered detrimental by producers because undesirable plants are allowed to grow undisturbed while the most desirable plants are severely grazed placing them at a competitive disadvantage leading to eventual plant community dominance by less-desirable plants from a forage perspective. Increased grazing pressure and uniform distribution of grazing animals eliminate this effect by forcing animals to graze the entire area of the pasture that they are allotted. This results in increased utilization and increased harvest efficiency which reportedly can increase a grazing unit's carrying capacity by 25 to 100% (Savory and Parsons 1980; Stuth et al 1981; Gompert 2010).

Even distribution of grazing animals at high densities is also reported to result in the even distribution of livestock excreta across the pasture. Nutrients in excreta are more readily available for use by the soil microbial community and become available to plants more rapidly than nutrients bound in plant material. Even distribution of excreta is considered by some to reduce the need for artificial fertilizers thus decreasing production costs (Peterson and Gompert 1995).

Practitioners report that the intensified hoof action in mob grazing breaks up water repellant soil crusts and incorporates plant litter, live plant material, and excreta into the soil increasing soil organic matter (SOM) inputs and nutrient cycle efficiency compared to other grazing systems (Peterson 2014b). It is also reported that trampled vegetation covers and protects soil from erosion increasing soil hydrologic function, seedbed preparation and germination rates (Savory 1983; Savory 2013).

Practitioners who use mob grazing methods report increases in vegetation production of 100 to 300% as well as improved plant diversity which they believe to be a result of improved soil function and fertility, and even distribution of grazing pressure. The increase in vegetation production would allow for increased stocking rate resulting in increased animal production and greater profits for producers while maintaining the ecological integrity of the ecosystem (Gompert 2010). No replicated research has been published on the effects of stocking densities common in mob grazing systems. Experimental evidence from less intensive grazing systems does not wholly support the claims associated with mob grazing.

This research was designed to test the hypothesis that mob grazing results in greater aboveground vegetation production and greater plant diversity while maintaining good animal performance through increased vegetation trampling, and to quantify the effects of mob grazing on pasture productivity, species diversity, forage utilization and harvest efficiency, as well as animal performance and forage quality when compared to more traditional grazing and harvest methods.

Study Site

The University of Nebraska - Lincoln Barta Brothers Ranch is approximately 2200 ha and located 11 km northwest of Rose, in Rock and Brown counties NE. About 100 ha of the ranch are subirrigated meadow. Approximately 10% of the 4.5 million ha of Sandhills is subirrigated meadow (Bleed and Flowerday 1998). Meadows are low, well watered, relatively level areas between elevated dune formations and can exceed a kilometer in width and several kilometers in length. Soils are fine sand well supplied with clay, silt, and organic matter, and are poorly drained. The water table is typically within 1 to 2 m of the soil surface and usually easily reached by plant roots. The Sandhills is a semi-arid region with a continental climate type and receives approximately 56 cm of precipitation annually (Bleed and Flowerday 1998).

Vegetation is a productive mixture of introduced cool-season grasses and forbs with native warm-season grasses, sedges, and rushes that typically yields 3500 to 5000 kg ha^{-1} of aboveground plant production. Dominant cool-season grasses include timothy (*Phleum pretense* L.), quackgrass (*Elymus repens* Gould), red-top (*Agrostis stolonifera* L.), Kentucky bluegrass (*Poa pratensis* L.), and Scribner panicum (*Panicum oligosanthes*

Schult. var. scribnerianum [Nash] Ferald). Native warm-season grasses include big bluestem (*Andropogon gerardii* Vitman), Indiangrass [*Sorghastrum nutans* (L.) Nash], and prairie cordgrass (*Spartina pectinata* Link). Common exotic forbs are the legumes red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.).Several species of native sedges (*Carex spp.)* and rushes (*Equisetum spp., Eleocharis spp.,* and *Juncus spp.*) are also common.

Mob grazing practitioners in the Nebraska Sandhills region typically mob graze meadows where water is plentiful and plant production is sufficient to achieve ultrahigh stocking densities in a reasonable number of moves each day. Approximately 27 ha of subirrigated meadow on the Barta Brothers ranch were designated for this study in 2010.

Materials and Methods

Grazing system treatment application began on Sandhills subirrigated meadow in May 2010. Prior to initiation of the study, the meadow was hayed annually in July. Five treatments were applied in a randomized complete block design with 2 replications. The 5 treatments were (1) a 120-pasture ultrahigh stocking density rotation (MOB) with a single grazing period, (2) a 4-pasture rotation with a single grazing period (4-PR-1), (3) a 4-pasture rotation with 2 grazing periods (4-PR-2), (4) a mid-July haying, and (5) a control (no harvest of live standing vegetation during the growing season). Each replication of the grazing treatments was comprised of the prescribed number of pastures. Electric fencing was used and cattle had drinking water and a mineral mixture available in each pasture. Grazing treatments were grazed by yearling steers with an average initial weight ranging between 320 and 360 kg.

The grazing season for the 4-PR-2 treatment was 90 days in 2010, and 80 days in 2011, 2012, and 2013. Grazing season length for the 4-PR-1 and MOB treatments was 60 days each year. Stocking rates varied among years but were constant among treatments within years (Table 2-1). Starting dates and stocking densities varied slightly among years and treatments (Table 2-1).

The 4-PR-2 was selected as a conventional method of grazing meadows with an early start date to take advantage of cool-season vegetation growth and a second grazing period to take advantage of new vegetation growth following the first grazing period. The MOB grazing period was designed to start later in the growing season in order to achieve optimum conditions for trampling 60% of the standing herbage which was the target for building soils according to Gompert (2010). As cool-season grasses, which dominate the meadow, enter the elongation/reproductive stage they have a higher stem to leaf ratio than during early vegetative growth. A high stem to leaf ratio increases the likelihood of plants being trampled (Gompert 2010). The 4-PR-1 had the same starting date and grazing season length as the MOB so that their effects could be compared directly. Stocking rate and starting grazing dates were adjusted in 2011 because animal performance in 2010 was poor, especially for the MOB and 4-PR-1 grazing treatments. Stocking rate was reduced to increase forage allowance and improve nutrient intake. Starting grazing dates for the MOB and 4-PR-1 grazing treatments were moved earlier in the growing season to increase the proportion of the grazing season with vegetative, high quality forage available for grazing. Stocking rate also was adjusted in late June 2013 because of insufficient forage biomass, likely a result of the 2012 drought and the cool dry spring of 2013. The cool dry spring of 2013 also delayed plant growth so starting grazing dates for all treatments were one week later in 2013 than in previous years (Table 2-1).

With the lower stocking rate in 2013, pasture size was reduced in the MOB and number of moves each day increased to maintain stocking density similar to previous years (Table 2-2). In 2010, 2011, and 2012, the two daily moves in the MOB occurred at 0700 hours and 1400 hours. The three daily moves in the MOB in 2013 occurred at 0700 hours, 1100 hours, and 1600 hours. The total area grazed each day was equal among years (Table 2-2). Each pasture of the 4-PR-1 rotation was 0.42 ha and was grazed for 13 to16 days each year. Each pasture of the 4-PR-2 rotation was 0.63 ha and was grazed for 8 to 12 days each occupation each year.

The hay plots (1.0 ha each) were harvested with a sickle bar mower and baled with a large round baler at a cutting height of 5 to 10 cm. The plots were to have been harvested in mid-July which is the average haying date for Sandhills meadows. The plots were harvested in early August in 2010. In 2011, the hay plots were not cut due to a lack of equipment and labor. The hay plots were harvested and baled in early-July in 2012 and 2013 when haying equipment was available.

Control plots (1.0 ha each) were not to be harvested until the dormant season. In 2010 sanding vegetation was cut and removed in November. In 2011, 2012, and 2013, vegetation on control plots was not cut and removed because equipment and labor were not available.

In 2011, two replications of a continuous grazing treatment were added to the meadow. One 60-day grazing period has been applied to these pastures beginning on the same date as the 4-PR-1 and MOB treatments. These pastures were grazed by four steers in 2011 and 2012 at a stocking density of 4 AU·ha^{-1}. Three steers grazed these pastures at a stocking density of 3 AU·ha^{-1} in 2013. Stocking rate was equal to all other grazing treatments in each year. Because they were not part of the original experiment, all vegetation data from these pastures are excluded from the analysis. They were used only for analysis of animal activity in 2013.

Net Primary Production

Net primary aboveground vegetation production was estimated at peak standing crop in the first week of August in 2012 and 2013. Ten 1-m^2 exclosures were randomly located in each replication of each of the grazing treatments prior to grazing in May each year. All standing live vegetation in one 0.25-m^2 quadrat was clipped at the soil surface within each exclosure and ten randomly located 0.25-m^2 quadrats were clipped in each replication of the control. Clipped vegetation was separated into standing live herbage (SLH) and standing dead herbage (SDH) and placed in separate marked paper bags. Litter (LIT) was also collected and placed in a marked bag. Samples were dried in a forced air dryer at 60^o C to a constant weight and weighed.

Trampling, Harvest Efficiency, and Utilization

Sampling occurred after each occupation of each pasture in the 4-PR treatments and four times throughout the grazing season in the MOB treatment in 2010, 2011, and 2013. Ten, 1-m^2 exclosures were randomly located in each pasture of the 4-pasture rotational treatments prior to occupation by cattle. When cattle were moved from a pasture, standing vegetation was clipped and litter gathered in a 0.25-m^2 quadrat placed within each exclosure. Standing vegetation was also clipped and litter gathered from a second 0.25-m^2 quadrat placed 1 m north of each exclosure. In the 4-PR-2 treatment, exclosure location was re-randomized prior to the second occupation. In MOB pastures, sampling occurred once every other week starting the second week of the grazing season. Ten, 0.25-m^2 quadrats were randomly located within each pasture sampled. Quadrats were clipped one day prior to the pasture being grazed. Post-grazing quadrats were located 1 m north of each pre-grazing quadrat location and were clipped one day post-grazing. In each quadrat, all herbage was hand clipped to the soil surface and litter was gathered. Herbage was sorted as SLH, SDH, LIT, and trampled herbage (TR). Samples were placed in separate, labeled paper bags, dried to a constant weight at 60^{o} C, weighed, and recorded. Trampled herbage was identified as current year's shoots that were unattached to the plant base or still attached but bent to a 45 degree angle or less from the soil surface. Biomass weights were used to calculate herbage yield to date, percent trampled, harvest efficiency, utilization, and instantaneous grazing pressure upon entry of and exit from each sampled pasture.

Herbage yield (kg·ha^{-1}) = PreSLH within a pasture ÷ pasture size in ha,

Percentage trampled (%) = (TR ÷ PreSLH) x 100,

Harvest efficiency (%) = [((PreSLH – (PostSLH + TR)) ÷ PreSLH] x 100,

Utilization (%) = [(PreSLH – PostSLH) ÷ PreSLH] x 100, Instantaneous grazing pressure at the time cattle were turned into the pasture ($AU \cdot Mg^{-1}$) = AUs in a pasture ÷ PreSLH in a pasture;

Instantaneous grazing pressure at the time cattle were removed from the pasture ($AU \cdot Mg^{-1}$) = AUs in a pasture ÷ PostSLH in a pasture;

Experimental unit was the 4 pastures combined in the each of the 4-PR-1 replications and the 4-PR-2 replications and the 120-pastures in each the MOB replications. Estimates of herbage yield, percentage trampled, harvest efficiency, utilization, and instantaneous grazing pressure were calculated for each pasture sampled and averaged over the experimental unit.

Basal Cover and Species Composition

Basal cover, relative species composition, and ground cover were estimated using the modified step-point method as outlined by Owensby (1973) in late June of 2010, 2011, 2012, and 2013. One hundred fifty randomly-selected points were sampled in each pasture of the 4-pasture, hay, and control treatments. Each replication of the MOB treatment was divided into eighths with 75 randomly-selected points sampled in each eighth. Ground cover at each point was recorded as bare ground, litter, or plant base. Plant base hits were identified by species. When the point was bare ground or litter, the nearest plant to the point was identified by species.

Forage Quality

For each clipping date, four pre-graze SLH sub-samples were selected randomly from the 10 sub-samples collected in each pasture. Two sub-samples were combined to create each of the samples which were used in forage quality determination. Samples were ground with a Wiley mill through a 1-mm screen. Crude protein analyses were done with a LECO FP-528 N analyzer (LECO, Inc., St. Joseph, MO) using standard methods (AOAC 1996). Neutral detergent fiber (NDF) analyses were conducted with an ANKOM Fiber Analyzer (Ankom Inc., Fairport, NY). For NDF analyses, sample bags were filled with 0.5 g of SLH sample ground to pass through a 1-mm screen. Bags were heat sealed and placed in a bag suspender in neutral detergent solution in the fiber analyzer. Samples were agitated for 90 minutes and rinsed three times with boiling distilled water. Bags were placed in a drying oven at 60° C and allowed to dry overnight before weighing.

Forage quality is reported separately for 2010 due to variation in sampling. Cattle grazing in the 4-PR-1 and MOB treatments started on 5 July, 2010, as opposed to 7 June in 2011, and 12 June in 2013. The late start date and the early termination date of grazing in 2010 make comparison with 2011 and 2012 inappropriate. Grazing dates in 2011 and 2013 were much more similar and are therefore analyzed and presented together.

Animal Performance

Animal performance was calculated as average daily gain (ADG) of each steer in each replication of each treatment. All steers are were limit fed for five days and then weighed for two consecutive days prior to the start of the grazing season at the Agricultural Research and Development Center (ARDC). The average of the two days weight was calculated for each steer and used as their beginning weight. Steers were delivered by truck to BBR and moved directly to the study pastures upon arrival. Following completion of the grazing season, animals were transported back to the

ARDC, and weighed by the same process used at the beginning of the grazing season to calculate ending weight. The difference in beginning and ending weight was divided by days grazing to calculate ADG for each steer. The 2010 weight gain data are excluded from this study due to the unexplained death of 11 steers and the early termination of the grazing season.

Animal Activity

In 2013, 2 steers were randomly selected within each replication of the 4-PR-1, MOB, and continuous treatments and each steer was fitted with an IceCube pedometer (IceRobotics Inc. Edinburgh Scotland). Pedometers sampled animal activity at a rate of 4 hz (4 samples second^{-1}) and summarized time standing, number and duration of laying bouts, and steps taken, every 15 minutes. Pedometers remained on the steers for the full 60-day grazing trial. Data were downloaded, summarized, and analyzed after the end of the grazing trial.

Analysis

Data were analyzed as a split-plot in time using the lsmeans statement in SAS (SAS 2010) for grazing pressure, aboveground SLH production and composition, utilization, forage quality, and animal activity and performance. Treatment was nested within year, which was nested within replication by block. Species composition was analyzed for change in relative composition of functional groups over time also using lsmeans in SAS. P values less than 0.05 were considered significant unless otherwise specified.

Results and Discussion

Precipitation and Growing Degree Days

Precipitation and growing degree days varied widely over the years of the study (Table 2-3). Precipitation from April through August of 2010 and 2011 was 57 and 24% above average, respectively. Precipitation from April through August 2012 was 56% below average placing the study site in severe drought most of the growing season. In 2013, precipitation was 94% of average for the growing season. Total growing degree days on 1 May in 2010 was within 10% of average. In 2011 and 2013, growing degree days by 1 May were 26% below average; whereas on 1 May 2012, total growing degree days were 51% above average. By the end of August in 2010, 2011, and 2013, growing degree days were within 5% of average. Growing degree days in 2012, however, were still 13% above average by late August.

Grazing Pressure

Instantaneous grazing pressure upon entering pastures differed significantly among treatments and years (Table 2-4). Grazing pressure did not differ between the 4-PR treatments in any year or among years. MOB grazing pressure was greater than either of the 4-PR treatments in all years and differed significantly among years. In 2010, 2011, and 2013, grazing pressure in the MOB treatment was 27, 25, and 37 times greater than the 4-PR pastures in the same years. Within the MOB treatment, 2011 grazing pressure was 21% greater than 2010. In 2013, grazing pressure in the MOB was 67% greater than 2010 and 38% greater than 2011 (Table 2-4). Instantaneous grazing pressure upon exiting pastures differed among treatments but not among years (Figure 2-1). Grazing pressure upon exiting a pasture in the MOB treatment averaged 67 times greater than in the 4-PR pastures.

Grazing pressure relates available forage to instantaneous animal demand and is a measure of grazing severity (Vallentine 2001). As grazing pressure increases, harvest efficiency and severity of defoliation generally increase. Grazing pressure was greater in the MOB treatment but MOB harvest efficiency was not different from the 4-PR-2 treatment and was lower than the 4-PR-1 (Figure 2-5). The increased grazing pressure upon exiting a pasture is a result of forage consumption and trampling by steers during the occupation of the pasture. Within the MOB treatment, significant difference between years 2010 and 2011 is likely a result of reduced plant production. Numerically, 2011 production was about 1000 kg ha^{-1} less than 2010. While this did not produce statistically significant differences in plant production between years ($p > 0.1$) (Johnson 2012), it appears that it was enough to significantly affect grazing pressure. The difference between 2011 and 2013 is likely a result of reduced pasture size and increased moves per day which resulted in slightly greater stocking density (Table 2-2). In 2010 and 2011, steers in the MOB treatment were moved through two pastures each day at stocking densities near 200,000 kg ha^{-1}. In 2013, ten fewer animals were used in each replication of the MOB requiring that steers be moved through three 0.04 ha pastures each day. While the reduced pasture size maintained stocking density over 200,000 kg ha^{-1}, it resulted in slightly greater stocking density in 2013 compared to 2010 and 2011 (Table 2-2) which significantly increased grazing pressure.

Annual aboveground plant production and composition

Annual aboveground plant production averaged 4160 kg ha^{-1} and did not differ among treatments or between 2012 and 2013. The year by treatment interaction in annual aboveground plant production approached significance with a $p = 0.079$. This is a result of the MOB being the only treatment to produce significantly more aboveground plant biomass in 2013 than in 2012. Several practitioners report observing increases in aboveground plant production in as little as one or two growing seasons (Peterson 2014a, Totten 2014, Kidwell 2010).

Wingeyer (2014), a post-doctoral research associate with the University of Nebraska – Lincoln, conducted ongoing on-ranch research examining mob grazing in the Sandhills (Wingeyer 2014) indicates there is no difference or only slight increases in aboveground plant productivity in mob grazed meadow areas compared to adjacent meadows that have been hayed or grazed in conventional grazing systems. One ranch that had been mob grazing subirrigated meadow for 9 years recorded the greatest increase in aboveground plant productivity with mob grazed pastures producing about 540 kg ha^{-1} more plant biomass (a 10 to 15% increase) than adjacent hayed areas of the meadow (Wingeyer 2014). Establishment of a mob grazing system can require significant investment of capital and labor. Practitioners often cite increased plant production or relatively high harvest efficiency as the primary source of returns to offset the investments required for mob grazing. Considering the relatively low harvest efficiency observed in this research (Figure 2-5), if an increase in production does not occur on the study site in several years of treatment, it is highly unlikely that this approach to mob grazing will be sustainable from a production perspective.

There was a year by treatment interaction for litter mass (Figure 2-2). Litter mass was greatest in the control and did not differ among the three grazing treatments. Litter mass in the three grazing treatments did not differ between 2012 and 2013. In the control, litter mass was 34% greater in 2013 than in 2012. Litter mass was 336 and 452% greater in the control than in the three grazing treatments in 2012 and 2013, respectively (Figure 2-2). The meadow on which these treatments were implemented was hayed annually prior to the initiation of the grazing experiment. Standing plant mass was cut and removed from the control plots in the 2010 dormant season but was not removed in the dormant season following the 2011, 2012 or 2013 treatments. The greater litter mass on the controls and the increase in litter in the control plots from 2012 to 2013 is likely a result of the lack of harvests of control plot vegetation from 2011 through 2013.

There was a year by treatment interaction for mass of standing dead vegetation but these interactions did not show any clear patterns of response to treatment (Table 2-5). In 2012 mass of standing dead vegetation was 92% greater in the control than in the grazing treatments ($p < 0.05$). In 2013, mass of standing dead was 115% greater in the 4-PR-1 and MOB than in the 4-PR-2 ($p < 0.05$). Mass of standing dead vegetation between 2012 and 2013 decreased 66% in the control and increased 77% in the 4-PR-1 and MOB ($p < 0.05$).

Forage Utilization, Trampling, and Harvest efficiency

Utilization

Utilization is the combined effects of trampling and consumption of live standing plant mass by grazing animals. With a percentage trampling target of 60% in the MOB treatment, greater utilization was expected in the MOB than the other treatments.

There was a year by treatment interaction for the percent of standing plant mass utilized (Table 2-6). In 2010, utilization in the MOB was 35 and 81% greater than in the 4-PR-1 and 4-PR-2 treatments, respectively. Utilization in the 4-PR-1 was 34% greater than the 4-PR-2 in 2010. Utilization in the 4-PR-1 and MOB treatments was 22 and 44% greater than the 4-PR-2 in 2011 and 2013 respectively. In the 4-PR-1, utilization was 31% greater in 2011 and 2013 than in 2010. In 2011, utilization in the 4-PR-2 treatment was 45% greater than 2010, and 18% greater than 2013. Utilization in the 4-PR-2 in 2013 was 22% greater than in 2010. Johnson (2012) hypothesized that the greater utilization in 2011 compared to 2010 was likely a result of an earlier starting grazing date in the MOB and 4-PR-1 in 2011. This seems unlikely because the difference in utilization from 2010 to 2011 was greatest in the 4-PR-2 which had similar start dates both years and because there was no increase in utilization in the MOB treatment which started earlier in 2011 than in 2010. The greater utilization in 2011 and 2013 compared to 2010 is possibly a result of reduced aboveground plant production. As mentioned previously, aboveground plant production was about 1000 kg ha^{-1} less in 2011 compared to 2010. While this did not produce statistically significant differences in yield between years ($p > 0.1$) (Johnson 2012), it may have been enough of a difference to significantly affect utilization. If mass of standing vegetation utilized was similar among years and less standing vegetation was available in 2011 and 2013, utilization would be greater as a percentage of available SLH in 2011 and 2013. The cause of decreased utilization in the 4-PR-2 from 2011 to 2013 is unclear.

Trampling

Percentage of SLH available for grazing that was trampled during the grazing period in MOB pastures was about 58% to 125% greater than in the 4-PR-1 and 4-PR-2, respectively (Figure 2-3). The increase in trampling in the MOB treatment is likely a result of stocking density. Visual observations found that trampling in the 4-PR treatments was patchy and uneven. Trampling in the mob treatment appeared to be quite uniform throughout each pasture, likely a result of greater animal activity levels in the MOB and increased grazing pressure from the greater stocking density (Table 2-12). The difference between 4-PR-1 and 4-PR-2 treatments approached significance with $p = 0.09$ (Figure 2-3). Percentage of SLH available for grazing that was trampled during the grazing period in 2011 was 57 and 60% greater than the percentage of SLH trampled in 2010 and 2013 respectively (Figure 2-4).

This research was designed with a target of 60% trampling in the MOB treatment. This level of trampling was reported to optimize the potential for increasing soil quality and function (Gompert 2010). While the target of 60% was reached (Figure 2-3), any changes in soil quality and function had not resulted in discernable increases in production by the end of the fourth grazing season. The cause of the increase in trampling in 2011 average over the three grazing treatments (Figure 2-4) is unclear.

Standing live herbage at sampling times did not differ among years. Both 2010 and 2011 were wetter than average years, but trampling in 2010 was less than 2011. Start date of grazing is not likely to be the cause as the 2011 and 2013 grazing seasons started within five calendar days of each other. This suggests the high trampling of 2011 was not simply a result of precipitation, plant production or start date, but is the result of some unknown effect. In personal communication, Wingeyer (2014) also reported relatively high levels of trampling of vegetation (46-61%) in 2013 on the mob grazed meadow of three Sandhills ranches.

Disappearance

Percentage of the SLH available for grazing that disappeared during the grazing period was 66% greater in the 4-PR-1 pastures than in the MOB pastures (Figure 2-5). Percentage of SLH available for grazing in the 4-PR-2 pasture did not differ from either the 4-PR-1 or MOB treatments. Disappearance did not differ among years but approached significance ($p = 0.07$) with disappearance of 39.8, 28.5, and 44.3% in 2010, 2011, and 2013, respectively. The reduction in disappearance in 2011 correlated with the increase in trampling in the same year.

Disappearance was assumed to represent harvest efficiency in this study. Greater than average harvest efficiencies are regularly reported by mob grazing practitioners but the data from this study do not show that. The MOB treatment in this research was designed to target 60% trampling, which was achieved. This limits harvest efficiency in the MOB treatment to a maximum of 40% if 100% utilization is achieved. Since 100% utilization is unlikely with rapid moves at 200,000 kg ha^{-1}, it is unlikely that harvest efficiency will improve as long as 60% trampling is achieved. Wingeyer (2014), reported harvest efficiencies in mob grazing systems on Sandhills ranches ranging from 33 to 43% at stocking densities ranging from 90,000 kg ha^{-1} to 300,000 kg ha^{-1}.

Botanical composition and ground cover

Cool-season Grasses

Cool-season grasses declined across all treatment from 2010 to 2013 (Table 2-7) and had a significant year by treatment interaction (Table 2-8). Cool-season grasses had declined 15%, 19%, 13%, and 40% in relative composition by 2013 relative to 2010 in the 4-PR-1, 4-PR-2, MOB, and control treatments respectively. The 40% decline in relative composition of cool-season grasses in the control was greater than in the grazing treatments (Table 2-8).

Annual climatic variation may have been the primary driving factor in the decrease in cool-season grasses in all grazing treatments and control plots. Extreme rainfall events resulted in inundated conditions over a large portion of the treatment area during the grazing season of 2011. Johnson (2012) stated that these conditions affected at least two sampling events during the summer of 2011 indicating that the area was likely inundated at least 10 and possibly as many as 20 days. Many cool-season grass species cannot tolerate saturated or inundated soil conditions for extended periods of time and may have drowned during this period. Random location of treatment plots placed the control plots in the lower wetter areas of the meadow. Effects of extended soil saturation and inundation probably would have been more severe in these plots than in plots in drier areas and may explain the more severe decline of cool-season grasses in the control treatments. In the following grazing season of 2012, the study area was in severe drought conditions for most of the growing season which also likely had a detrimental effect on cool-season grasses. Visual assessment of the meadow indicated most cool-season grasses were dormant with little green leaf tissue by early August 2012. Several individual cool-season grasses may have succumbed to the drought for lack of water, or to the following winter as a result of insufficient energy storage. Why this would affect the lower and likely wetter control plots more severely than the higher grazed plots is unclear.

Warm-Season Grasses

There was a significant year effect on relative composition of warm-season grasses (Table 2-7). In 2012, relative composition of warm-season grasses was 4.8% greater than 2010 and 5.4% greater than 2011. Drought conditions in 2012 would have favored warm-season grasses over cool-season grasses or the water dependent sedges and rushes on the meadow. This may explain the increase in relative composition during 2012.

Sedges, Rushes, and Forbs

There was a significant year effect on relative composition of sedges (Table 2-7). Sedges increased in relative composition across all treatments 17.5% from 2010, to 2013. Percentage sedge composition increased 9% from 2010 to 2011 and 6% from 2011 to 2012 which did not differ from 2013. It is expected that sedges would be the functional group to increase with the high rainfall in 2010 and 2011and fill the void left by the decline in cool-season grasses. It appears unusual however, that their composition increased in the 2012 drought and remained high in 2013.

There was no difference in relative composition of rushes except in 2012 (Table 2-7). Rushes decreased in relative composition by 4.2% in 2012 compared to 2010, and 2011, but recovered in 2013. This decrease in rushes in 2012 is likely a result the extreme drought conditions during the 2012 growing season.

Relative composition of forbs was 3.3% greater in 2013 than the average of 2010 - 2012 (Table 2-7). This effect was seen across all treatments. Field observation suggests this increase in forbs was primarily white clover (*Trifolium repens L.)* which is highly opportunistic (Carlson et al. 1985). There was a noticeable increase in forbs throughout the Sandhills region in 2013, presumably triggered by the drought conditions of 2012 (Volesky 2014). It is highly probable that the drought of 2012 resulted in the death, or reduced growth of other species leaving resources available for exploitation by opportunistic forbs in 2013.

Increasing native warm-season grasses and forbs is a benefit of mob grazing seen by many producers (Peterson C. 2014). These benefits are yet to emerge in this study area. While there have been multiple significant shifts in composition of functional groups over the course of this study, they appear to be responding more closely to annual climatic variation than to treatment effects.

Ground Cover

There was a significant year effect in the relative composition of ground cover (Table 2-9). Litter cover increased 6% from 2010 to 2012 and did not decrease in 2013. Relative composition of bare ground and plant base responded inversely to litter. Relative composition of bare soil decreased 4% from 2010 to 2012 (Table 2-9). Relative composition of the soils surface occupied by plant base decreased 1.6% from 2010 to 2012 and increased 0.8% from 2012 to 2013 (Table 2-9). Changes in relative composition of soil surface occupied by plant base may respond more closely to climatic variation than treatment effects. Drowning during the inundation of 2011 and death under drought conditions in 2012 would explain the decrease in plant base covered soil from 2010 through 2012. Relatively normal precipitation in 2013 may have aided in recovery, increasing plant base cover area in that year.

There was also a significant treatment effect in percent soil surface covered by plant base (Figure 2-6). Percent soil surface occupied by plant base in the 4-PR-2 was about 0.9 and 0.8% greater than the MOB and control respectively. Percent soil surface occupied by plant base in the 4-PR-1 was 0.6% greater than the MOB. The differences in plant base soil cover among grazing treatments does not appear to have changed over time and may be the result of random placement rather than treatment response.

Forage Quality

NDF

There were no significant differences in NDF between treatments or sample dates in 2010. NDF averaged 65.8% across all dates and treatments in 2010.

There was a year by treatment interaction in 2011 and 2013 (Table 2-10). In 2011, NDF content of available SLH in the 4-PR-2 pastures was 3.4 and 4.8% lower than the 4-PR-1 and MOB pastures respectively. In 2013, NDF content of available SLH did not differ. Standing live herbage in the 4-PR-1 and 4-PR-2 pastures in 2013 had 2.9 and 6.2% greater NDF content than in 2011, respectively. In the MOB pastures, the 2.1% difference in NDF content approached significance at $p = 0.061$. There was no significant change in NDF over the course of the grazing season in either year.

The cause of the greater NDF in 2013 compared to 2011 is not fully known, but may be correlated with the increase in relative composition of sedges outlined above. Sedges are generally lower quality forage than cool-season grasses which have decreased across the treatment area. Sedges contain a greater relative concentration of structural carbohydrates than grasses, which would increase NDF and decrease forage quality.

Crude Protein

Crude protein of standing herbage was affected by treatment only in 2010. Johnson (2012) reported that significant treatment by date interactions ($p < 0.1$) were found in 2010 (Table 2-11). Crude protein content did not differ among treatments during the first cycle of the 4-PR-2 pastures but there was 43% greater CP content in the second cycle of the 4-PR-2 pastures while CP content in 4-PR-1 and MOB pastures remained unchanged. Johnson (2012) hypothesized that the increase in CP following the first occupation of the 4-PR-2 pastures was the result of increased prevalence of red and white clover which took advantage of the available resources becoming more available during the second occupation but evidence to support this is purely anecdotal. It is likely that the increase in CP content during the second cycle of the 4-PR-2 is a result of new vegetative growth following the first cycle.

Crude protein content averaged 7.4% in 2011 and 2013. No differences were found between treatments, dates, or years. CP did not significantly increase in the 4-PR-2 treatment and did not decline in the 4-PR-1 or MOB treatments. This seams contradictory to the concept that CP content declines as plants mature advances. It is possible that CP content in the 4-PR-1 and MOB treatments did not decline significantly because the plants were already in elongation stage by the early sample dates of the grazing season.

Some mob grazing practitioners believe that mob grazing allows them to provide more nutritious diets to their animals by regularly presenting them with fresh forage (Smith 2014, Totten 2014). These practitioner's objectives are more focused on nutrition than trampling and use mob grazing for a short period each grazing season when forage is near peak nutritional value.

Animal Activity

There was a treatment by date interaction for animal activity in 2013 (Table 2-12). In late-June, animals in the MOB pastures took 18.5% more steps each day than steers in the 4-PR-1. Steers in the MOB pastures took 14% more steps each day than steers in the continuous pastures which approached significance with a p value = 0.055. For all three sampling dates in July and in early August, steers in the MOB took 50% more steps each day than steers in either of the other treatments. In late-July steers in the 4-PR-1 pastures took 41% more steps each day than steers in the continuous treatment.

The increase in animal activity in the MOB pastures is likely a result of the multiple daily moves and pasture shape. MOB steers in 2013 were moved three times daily (Table 2-2) through pastures measuring only 4 m wide and 95 m long. While each move may contribute to high activity levels, anecdotal observation indicated than this long rectangular pasture shape favored increased animal activity. As steers entered a pasture, the first steers to enter begin grazing almost immediately forcing the remainder of the steers to travel around them to obtain new forage. This perpetuated a leapfrog effect, in which an individual may have had to travel the length of the pasture to circumvent the rest of the herd and find fresh forage. Leapfrogging continued until steers became concentrated at the end of the pasture and began the process again returning to the end where they originally entered the pasture.

Animal Performance

Animal performance differed significantly between grazing treatments and among years (Figure 2-7). As mentioned in the Methods section, animal gains data are not available for 2010.

Average daily gains (ADG) in the 4-PR-2 treatment differed among years but were greater than the 4-PR-1 and MOB treatments in all years. The 4-PR-1 treatment had greater ADG than the MOB treatment in 2011 and 2012 but was not different from the MOB in 2013. In 2013, ADG in the MOB was significantly greater than in 2011. Lower ADG in 2012 compared to 2013 in the 4-PR-2 pastures is likely related to precipitation. The lack of rainfall in the 2012 season severely limited regrowth in 4-PR-2 pastures compared to 2011 providing steers with a less nutritious diet in the second half of the summer.

The difference in ADG between the 4-PR-1 and 4-PR-2 is difficult to explain. There was no discernable difference in NDF or CP content or harvest efficiency between the treatments. The high ADG of the 4-PR-2 steers is likely the result of steers establishing grazing lawns in their first occupation of a pasture, and then concentrating grazing on highly nutritious regrowth on these lawns during the second occupation. Visual assessment of the 4-PR-2 treatments indicated that these grazing lawns had a tendency to establish on approximately the same area each grazing season. This is likely a result of steers avoiding areas with high concentrations of standing dead residual from the previous year. Random sampling within the four pasture treatment would not favor grazing lawns over more mature stands of forage which may have resulted in the true effects of established lawns on the quality of forage available to steers to be diluted. Decreased gains in the MOB treatment are likely a result of high grazing pressure and limited forage intake due to the high levels of trampling. Forage intake requirements of cattle are estimated to be 11.8 kg AU^{-1} (National Research Council 1996). Calculation of SLH disappearance for 2010, 2011 and 2013 estimates intake in the MOB treatment at approximately 6.3 kg AU^{-1}, only 53% of required. Gompert (2010) found that 21% of producers experience an increase in animal production in a mob grazing system, while 58% see no change and 21% see a decrease in animal production.

Management Implications

Ultrahigh stocking density grazing appears to be an effective method of increasing SLH trampling compared to a traditional four-pasture rotation. Trampling in the MOB treatment of this study averaged 60% which was the target level of trampling. Mob grazing practitioners have indicated this level of trampling as the optimum level for increasing soil function. In the fourth year of this study, the increased trampling in the MOB treatment had not resulted in any significant changes in SLH production or species composition compared to traditional four-pasture rotations. While several practitioners claim to have seen grasslands respond in as little as one or two years, changes in production and species composition may take much longer to respond to grazing treatments. Continuing this research would allow trends to appear that may only be developing and not visible at this time.

Mob grazing is also promoted as a method of increasing harvest efficiency. In this study, a stocking density of around 200,000 kg ha^{-1} did not produce an increase in harvest efficiency, likely as a result of the high rate of trampling which limited forage available for consumption. Mob grazing does not seem realistic from a livestock production perspective if 60% trampling is desired. At 60% trampling, harvest efficiency is limited requiring moderate stocking rates or reduced animal intake which limits animal production. This low animal performance makes mob grazing very difficult to justify from an animal production perspective. Significant increases in SLH production would be required to offset the effects of mob grazing on animal performance as well as the additional infrastructure and labor required in a high management intensive grazing system like mob grazing.

Some practitioners use stocking densities greater than 200,000 kg ha^{-1} to achieve greater harvest efficiency. Improving harvest efficiency through higher stocking densities and additional moves per day would either increase animal individual animal performance or support more animals on equal land area. This would require a reduction in trampling and may limit the proposed benefits of high levels of trampling in producing more SLH. Beginning grazing earlier in the growing season might improve animal performance in mob grazing systems by allowing animals to take advantage of more nutritious early growth. This would likely also decrease trampling as there would be less available forage and with a higher leaf to stem ratio, standing herbage would be more likely to be consumed than trampled. Targeting high trampling or high harvest efficiency is a management decision that will depend on producer goals and objectives.

At the conclusion of the fourth year of this study, the 4-PR-2 grazing treatment had consistently produced greater individual animal performance than the 4-PR-1 and the

MOB at the same stocking rate. Aboveground primary production has shown no advantage to mob grazing and no disadvantage to four-pasture rotations. The MOB treatment produced significantly greater levels of vegetation trampling which may equate to greater long-term productivity. Data from 2013 alone suggests that aboveground primary production may be responding positively to mob grazing, but additional sampling will be needed during subsequent years to confirm or deny the existence of such a response.

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Figures and Tables

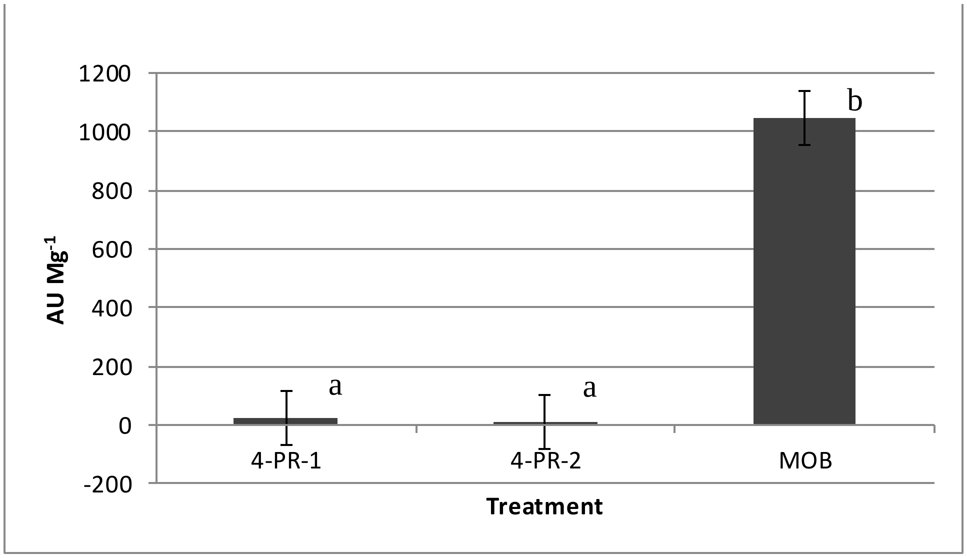

Figure 2-1: Instantaneous grazing pressure (AU Mg^{-1}) upon exiting a pasture for the four-pasture rotation with a single grazing occupation (4-PR-1), the four-pasture rotation with two grazing occupations (4-PR-2), and the ultrahigh stocking density rotation (MOB). Within treatments, between years, different lowercase letters significantly differ ($p < 0.05$).

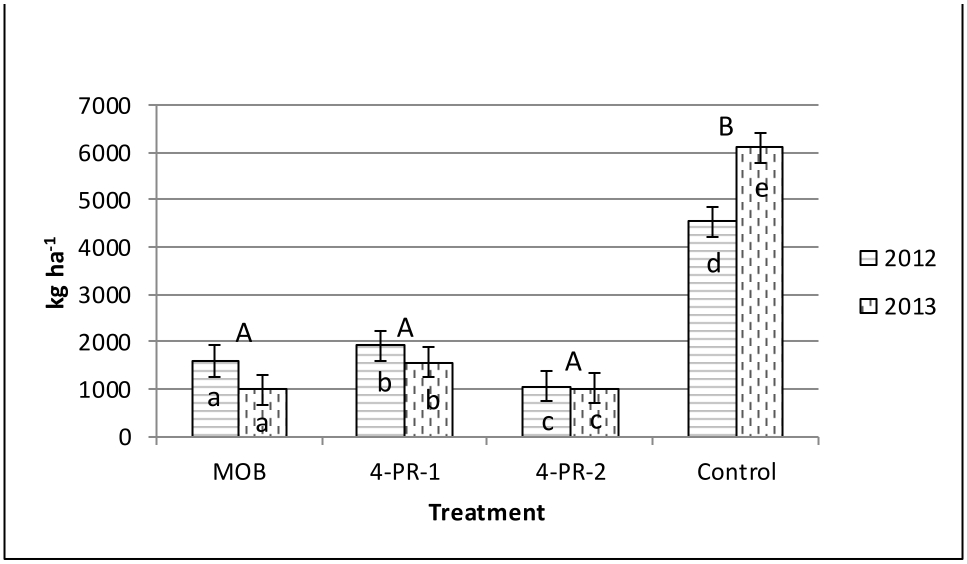

Figure 2-2 Litter biomass (kg ha^{-1}) in the four-pasture rotation with a single occupation (4-PR-1), the four pasture rotation with two occupations (4-PR-2), the ultrahigh stocking density rotation (MOB), and the control treatment in 2012 and 2013. Between treatments, different uppercase letters significantly differ ($p < 0.05$). Within treatments, between years, different lowercase letters significantly differ ($p < 0.05$).

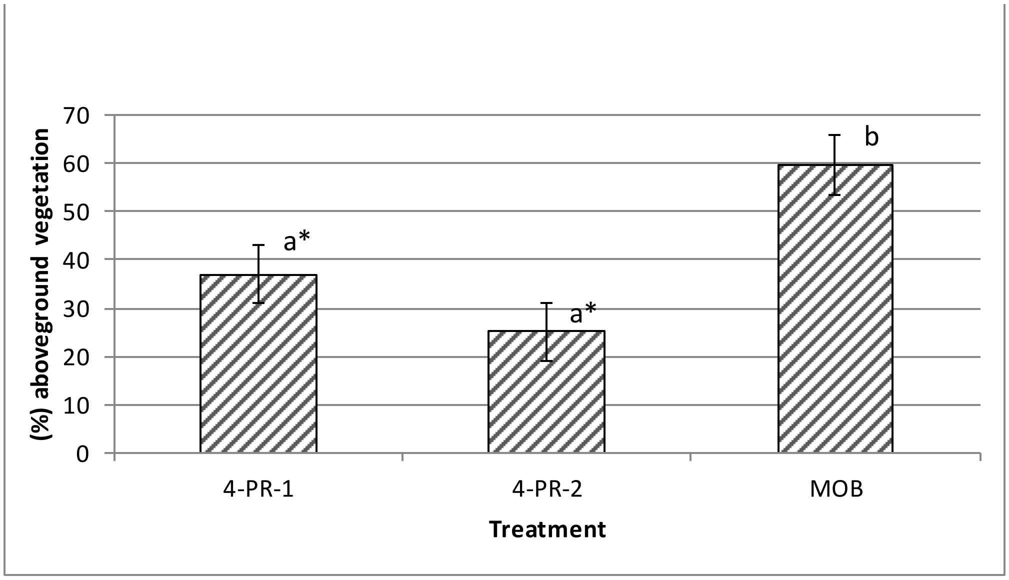

Figure 2-3. Trampled standing live herbage (%) in the four-pasture rotation with a single occupation (4-PR-1), the four pasture rotation with two occupations (4-PR-2), the ultrahigh stocking density rotation (MOB), and the control treatment for 2010, 2011, and 2013. Treatments with different letters significantly differ ($p < 0.05$). (*) approaches significance ($0.1 > p > 0.05$).

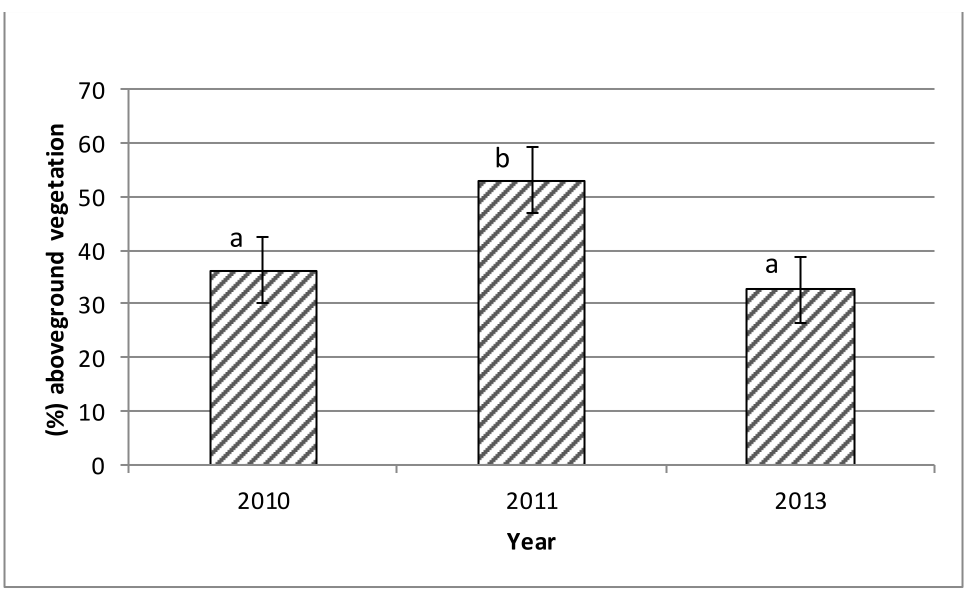

Figure 2-4: Trampled standing live herbage (%) in 2010, 2011, and 2013. Years with different letters significantly differ ($p < 0.05$).

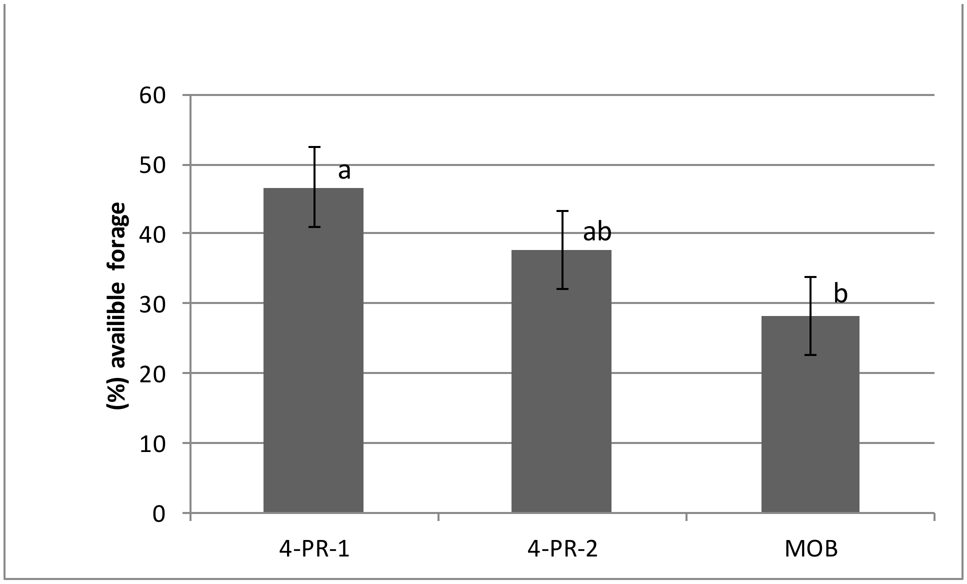

Figure 2-5. Disappearance of standing live herbage (%) in the four-pasture rotation with a single occupation (4-PR-1), the four pasture rotation with two occupations (4-PR-2), and the ultrahigh stocking density rotation (MOB) for 2010, 2011, and 2013. Treatments with different letters significantly differ ($p < 0.05$).

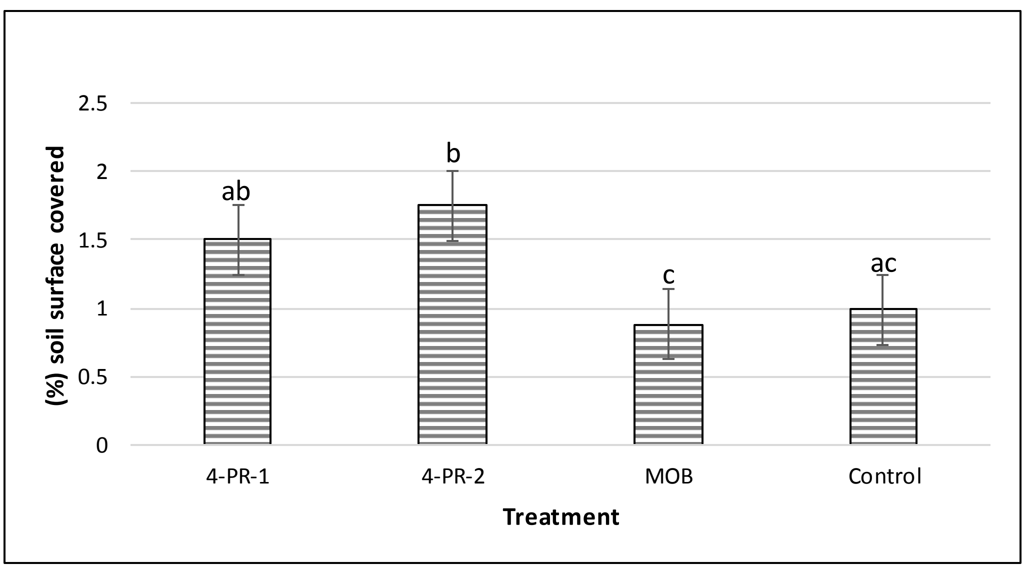

Figure 2-6. Relative composition of soil surface covered by plant base in the four-pasture rotation with a single occupation (4-PR-1), the four pasture rotation with two occupations (4-PR-2), the ultrahigh stocking density rotation (MOB), and the control treatment. Treatments with different letters significantly differ ($p < 0.05$).

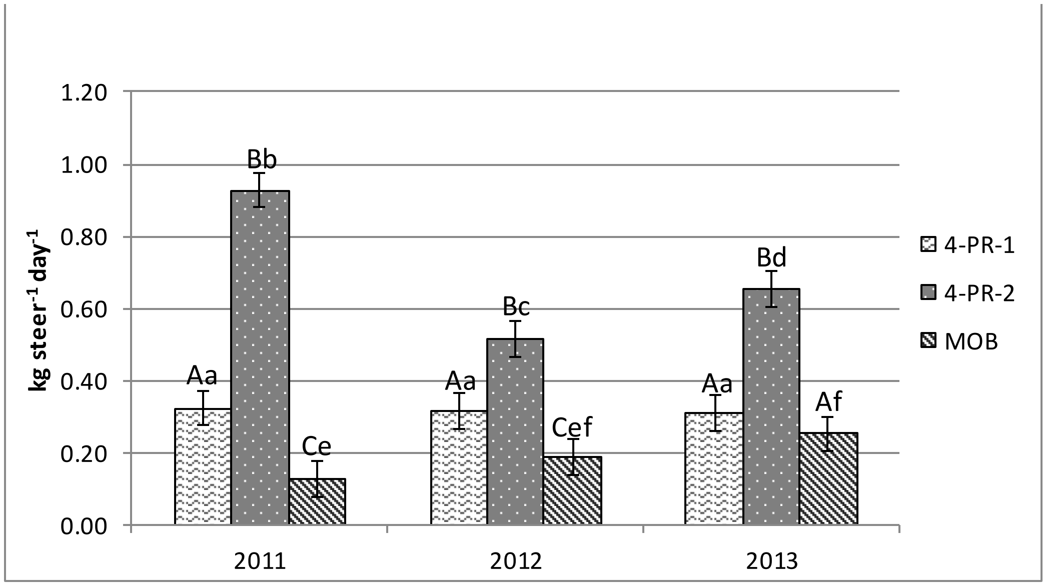

Figure 2-7. Average daily gain (kg steer^{-1} day^{-1}) in the four-pasture rotation with a single occupation (4-PR-1), the four pasture rotation with two occupations (4-PR-2), and the ultrahigh stocking density rotation (MOB) for 2011, 2012, and 2013. Treatments with different uppercase letters significantly differ within year ($p < 0.05$). Treatments with different lowercase letters significantly differ among years ($p < 0.05$).

Table 2-1. Number of steers (hd), turn in date (Start), stocking rate (AUM ha^{-1}), number of pastures (Past), stocking density as animal unit demand per unit land area (AU ha^{-1}), and stocking density as live animal weight per unit land area (kg ha^{-1}), in the four pasture rotation with a single occupation (4-PR-1), the four pasture rotation with two occupations (4-PR-2) and the 120 pasture mob-grazing rotation (MOB), in 2010, 2011, 2012 and 2013.

Year	hd	Start	AUM ha^{-1}	Past	AU ha^{-1}	kg ha^{-1}
	----------(4-PR-1)----------					
2010	10	July 1	8.2	4	16	7,472
2011	9	June 7	7.4	4	15	6,725
2012	9	June 5	7.4	4	15	6,725
2013	7	June 12	6.1	4	13	5,997
	----------(4-PR-2)----------					
2010	10	May 19	8.2	4	11	4,982
2011	10	May 18	7.4	4	11	4,982
2012	10	May 22	7.4	4	11	4,982
2013	7	May 29	6.1	4	9	3,998
	----------(MOB)----------					
2010	40	July 1	8.2	120	494	224,170
2011	36	June 7	7.4	120	445	201,753
2012	36	June 5	7.4	120	445	201,748
2013	26	June 12	6.1	180	515	233,880

Table 2-2. Number of steers (hd), stocking density (kg ha^{-1}), number of moves each day (moves), hectares in each pasture (ha $past^{-1}$) and hectares grazed each day (ha day^{-1}) in the ultrahigh stocking density grazing rotation in 2010, 2011, 2012 and 2013

Year	hd	kg ha^{-1}	moves	ha $past^{-1}$	ha day^{-1}
2010	40	224,170	2	0.06	0.12
2011	36	201,753	2	0.06	0.12
2012	36	197,780	2	0.06	0.12
2013	26	233,880	3	0.04	0.12

Table 2-3. Monthly precipitation (cm) and cumulative growing degree days (base 4.4° C or 40° F) (GDD) for the growing season in 2010 - 2013 and the 20 year mean

Year	April	May	June	July	August	April - Aug
	(cm)					
2010	8.92	8.71	26.77	5.92	7.06	57.38
2011	5.21	9.45	15.01	6.4	8.99	45.06
2012	10.31	3.53	1.19	0.76	4.62	20.41
2013	4.78	9.25	10.9	1.98	7.42	34.33
Mean	6.75	8.04	10.06	6.02	5.6	36.47
	(GDD)					
2010	573	1064	1848	2761	3653	9899
2011	460	940	1687	2643	3533	9263
2012	941	1537	2356	3298	4123	12255
2013	458	1004	1736	2595	3489	9282
Mean	623	1157	1905	2804	3661	10150

Table 2-4. . Instantaneous grazing pressure (kg live animal weight kg^{-1} SLH) of the four-pasture rotation with a single grazing occupation (4-PR-1), the four-pasture rotation with two grazing occupations (4-PR-2), and the ultrahigh stocking density rotation (MOB).

Treatment	2010	2011	2013
	----------	----------	----------
4-PR-1	2.72^{Aa}	3.69^{Aa}	3.42^{Aa}
4-PR-2	2.99^{Aa}	3.83^{Aa}	3.69^{Aa}
MOB	78.35^{Ba}	94.56^{Bb}	130.81^{Bc}

[1]Different uppercase letters within columns differ ($p < 0.05$)
[2]Different lowercase letters within rows differ ($p < 0.05$)

Table 2-5. Standing dead vegetation (kg ha^{-1}) in the four pasture rotation with a single occupation (4-PR-1), the four pasture rotation with two occupations (4-PR-2), the 120 pasture ultrahigh stocking density rotation (MOB), and the control treatment in 2012 and 2013.

Treatment	2012	2013
	----------(kg ha^{-1})----------	
4-PR-1	362^{ABa}	501^{Aa}
4-PR-2	304^{Aa}	222^{Bb}
MOB	177^{Aa}	455^{Ab}
Control	540^{Ba}	325^{ABb}

[1]Different uppercase letters within columns differ ($p < 0.05$)
[2]Different lowercase letters within rows differ ($p < 0.05$)

Table 2-6. Utilization of standing live herbage (%) in the four pasture rotation with a single occupation (4-PR-1), the four pasture rotation with two occupations (4-PR-2), and the 120 pasture ultrahigh stocking density rotation (MOB) in 2010, 2011, and 2013.

Treatment	2010	2011	2013
	(%)		
4-PR-1	65.4^{Aa}	84.7^{Ab}	85.0^{Ab}
4-PR-2	48.7^{Ba}	70.6^{Bb}	60.1^{Bc}
MOB	88.3^{Ca}	89.1^{Aa}	86.1^{Aa}

[1]Different uppercase letters within columns differ ($p < 0.05$)
[2]Different lowercase letters within rows differ ($p < 0.05$)

Table 2-7. Relative composition (%) of plant functional groups of warm-season grasses (C4 Grass), cool-season grasses (C3 Grass), sedges, rushes, and forbs, by year since 2010.

Group	2010	2011	2012	2013
	(%)			
C4 Grass	7^{a}	6^{a}	12^{b}	10^{ab}
C3 Grass	58^{a}	48^{b}	43^{c}	35^{d}
Sedges	17^{a}	26^{b}	32^{bc}	34^{c}
Rushes	11^{a}	12^{a}	7^{b}	11^{a}
Forbs	8^{a}	8^{a}	6^{a}	10^{b}

[1]Different letters within rows differ ($p < 0.05$)

Table 2-8. Cool-season grasses composition (%) in four pasture rotation with a single grazing occupation, the four-pasture rotation with two grazing occupations, the 120 pasture ultrahigh stocking density rotation (MOB), and the control, since 2010.

	Cool-season Grasses			
Treatment	2010	2011	2012	2013
	(%)			
MOB	57^{Aa}	49^{Aab}	49^{Aab}	44^{Ab}
4-PR-1	65^{Aa}	52^{Ab}	51^{Ab}	46^{Ab}
4-PR-2	59^{Aa}	50^{Ab}	44^{Abc}	38^{Ac}
Control	50^{Aa}	42^{Ab}	28^{Bc}	10^{Bd}

[1]Different uppercase letters within columns differ ($p < 0.05$)
[2]Different lowercase letters within rows differ ($p < 0.05$)

Table 2-9. Ground cover (%) of litter, bare soil, and plant base in 2010, 2011, 2012, and 2013.

Cover	2010	2011	2012	2013
	(%)			
Litter	93.0^{a}	95.8^{ab}	98.9^{c}	96.8^{bc}
Bare soil	4.9^{a}	3.2^{ac}	0.6^{b}	1.9^{bc}
Plant base	2.1^{a}	1^{bcd}	0.5^{c}	1.3^{d}

[1]Different letters in rows differ ($p < 0.05$)

Table 2-10. NDF (%) in in the 4-pasture rotation with a single grazing period (4-PR-1), 4-pasture rotation with 2 grazing periods (4-PR-2), and the ultrahigh stocking density rotation (MOB) in 2011 and 2013.

Treatment	2011	2013
	-----------------------------(%)-----------------------------	
4-PR-1	66.1^{Aa}	69.0^{Ab}
4-PR-2	62.7^{Ba}	68.9^{Ab}
MOB	67.5^{Aa*}	69.6^{Aa*}

[1]Different uppercase letters within columns differ ($p < 0.05$)
[2]Different lowercase letters within rows differ ($p < 0.05$)

Table 2-11. Crude protein content (%) in the 4-pasture rotation with a single grazing period (4-PR-1), 4-pasture rotation with 2 grazing periods (4-PR-2), and the ultrahigh stocking density rotation (MOB) in 2010. (Johnson 2012).

Date	4-PR-1	4-PR-2	MOB
	----------------------------------(%)----------------------------------		
1-15 Jul	6.7^{Aa}	6.7^{Aa}	7.0^{Aa}
16-31 Jul	6.2^{Aa}	7.7^{Bb}	6.6^{Aa}
Aug	6.8^{Aa}	9.7^{Cc}	6.6^{Aa}

[1] Different uppercase letter within columns differ ($p < 0.10$).
[2] Different lowercase letters within rows differ ($p < 0.10$).

Table 2-12. Daily animal activity (steps steer^{-1} day^{-1}) in the four-pasture rotation with a single occupation (4-PR-1), the 120 pasture ultrahigh stocking density rotation (MOB), and the continuous grazing treatment in 2013.

Treatment	18 June	1 July	15 July	26 July	7 Aug
	---------------------------------(step day^{-1})-------------------------------------				
4-PR-1	4184^{Aa}	4771^{Aab}	4823^{Ab}	3277^{Ac}	2740^{Ac}
MOB	4777^{Aa}	6781^{Bb}	5739^{Bc}	5079^{Ba}	5379^{Bac}
Continuous	4031^{Aa}	4602^{Aab}	4800^{Ab}	2605^{Cc}	2715^{Ac}

[1]Different uppercase letters within columns differ ($p < 0.05$)

[2]Different lowercase letters within rows differ ($p < 0.05$)

Chapter 3:

Forage Utilization, Trampling, and Harvest Efficiency among Ultrahigh Stocking Densities on Nebraska Sandhills Meadow

Introduction

Ultrahigh stocking density grazing, or mob grazing, is loosely defined as grazing livestock animals at stocking densities of 200,000 kg ha^{-1} or greater. This is accomplished by limiting the area available to animals to very small paddocks and usually requires that animals be moved multiple times each day. Some practitioners have found that stocking densities near 200,000 kg ha^{-1}, while high, are insufficient to accomplish their objectives. Increasing stocking density to as high as 1,000,000 kg ha^{-1}, has been reported to increase harvest efficiency and reduce trampling of standing live herbage (Peterson 2014).

Sub-dividing pastures has long been accepted as a method of increasing uniformity of utilization (Hart et, al. 1993). Norton (1994) hypothesized that smaller paddocks and higher stocking densities increases forage available to grazing animals because they encounter forage in all areas of the pasture. Harvest efficiency can be defined as the amount or proportion of available forage that is consumed by grazing animals. Increasing harvest efficiency is a point of focus for livestock producers as animal production is directly correlated with both the quality and quantity of forage harvested from grassland. Increasing harvest efficiency would allow producers to increase animal production per unit land area. The prime objective of sub-dividing pastures and increasing grazing distribution is that it result in enhanced forage utilization which, if realized, has been reported to increase carrying capacity as much as 25 to 100% (Savory and Parsons 1980; Stuth et al 1981). Garrish and Morrow (1999) reported a moving livestock every three days in a MIG system increased harvest efficiency to 68%.

On the other hand, in Texas, an increase in rotation intensity from a 14 pasture rotation to a 42 pasture rotation did not result in any increase in harvest efficiency at like stocking rates (Heitschmidt et al 1987a). Increasing harvest efficiency allows more live animal production to occur from the same amount of forage compared to less efficient systems. This allows producers to reduce production costs and increase total output from the same parcel of land.

Reduced trampling may interfere with some of the proposed ecological benefits of mob grazing such as increased soil quality, reduced erosion, improved nutrient cycling, and increased forage production. Trampling live vegetation places plant material in direct contact with the soil surface. This reportedly protects the soil and makes the trampled plant material readily available to soil microbes for decomposition which is said to increase soil organic matter content. Soil organic matter is directly tied to soil water holding and cycling capacities as well as fertility and production capability. Gompert (2010) suggested that trampling 60% of available standing live herbage would optimize the rate at which soils were improved and vegetation production would increase.

The ability to alter the relative percent of standing live herbage that is harvested or percentage trampled by grazing animals by manipulating stocking densities between 200,000 and 1,000,000 kg ha^{-1} would be a powerful tool for mob grazing practitioners. This would allow them to alter harvest efficiency and trampling throughout the grazing season as objectives and livestock requirements change. Most mob grazing practitioners have the ability to adjust pasture size and stocking density with relative ease through the use of portable temporary fence commonly used in such operations.

Research was conducted to quantify the effects of a variety of ultrahigh stocking densities on utilization, harvest efficiency, and trampling of available standing live herbage on subirrigated Sandhills meadow.

Study Site

The University of Nebraska - Lincoln Barta Brothers Ranch is approximately 2200 ha and located 11 km northwest of Rose, in Rock and Brown counties NE. About 100 ha of the ranch are subirrigated meadow. Approximately 10% of the 4.5 million ha of Sandhills is subirrigated meadow (Bleed and Flowerday 1998). Meadows are low, well watered, relatively level areas between elevated dune formations and can exceed a kilometer in width and several kilometers in length. Soils are fine sand well supplied with clay, silt, and organic matter, and are poorly drained. The water table is typically within 1 to 2 m of the soil surface and usually easily reached by plant roots. The Sandhills is a semi-arid region with a continental climate type and receives approximately 56 cm of precipitation annually (Bleed and Flowerday 1998).

Vegetation is a productive mixture of introduced cool-season grasses and forbs with native warm-season grasses, sedges, and rushes that typically yields 3500 to 5000 kg ha^{-1} of aboveground plant production. Dominant cool-season grasses include timothy (*Phleum pretense* L.), quackgrass (*Elymus repens* Gould), red-top (*Agrostis stolonifera* L.), Kentucky bluegrass (*Poa pratensis* L.), and Scribner panicum (*Panicum oligosanthes* Schult. var. scribnerianum [Nash] Ferald). Native warm-season grasses include big bluestem (*Andropogon gerardii* Vitman), Indiangrass [*Sorghastrum nutans* (L.) Nash], and prairie cordgrass (*Spartina pectinata* Link). Common exotic forbs are the legumes red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.).Several species of native sedges (*Carex spp.)* and rushes (*Equisetum spp., Eleocharis spp.,* and *Juncus spp.*) are also common.

Mob grazing practitioners in the Nebraska Sandhills region typically mob graze meadows where water is plentiful and plant production is sufficient to achieve ultrahigh stocking densities in a reasonable number of moves each day. Approximately 27 ha of subirrigated meadow on the Barta Brothers ranch were designated for this study in 2010.

Materials and Methods

Experimental Design

Four stocking density treatments were compared during 4-day grazing trials in two replications of the existing mob grazing experiment described in chapter 2. The grazing trials were conducted from 25 June to 28 June and 23 July to 26 July in 2012, and from 7 July to 10 July and 29 July to 1 August 2013. Thirty-six yearling steers in 2012 and 26 yearling steers in 2013 were used in each replication. Treatments included stocking densities of approximately 108,000 kg ha^{-1} (1x), 216,000 kg ha^{-1} (2x), 432,000 kg ha^{-1} (4x), and 864,000 kg ha^{-1} (8x). In 2012, densities were achieved by grazing 0.12 ha daily, as one paddock (0.12 ha), two paddocks (0.06 ha), four paddocks (0.03 ha), and eight paddocks (0.015 ha) for the 1x, 2x, 4x and 8x treatments respectively (Figure 3-1). In 2013, stocking rate was reduced due to reduced standing live herbage resulting from the drought of 2012 and a cool dry spring. Reduced stocking rates on the meadow required rotation through 3, 0.04 ha pastures day^{-1} to achieve the 216,000 kg ha^{-1} required for the 2x treatment and graze the allotted 0.12 ha. Consequently the 4x and 8x treatments in 2013 consisted of six 0.02 ha pastures, and twelve 0.01 pastures moves per day, respectively. The 1x treatment in 2013 consisted of one 0.08 ha pasture allotted at 0700 hours each day, followed by an additional 0.04 ha at 1600 hours with sampling conducted only in the 0.08-ha pasture for that day.

Rotation Schedule

When not involved in this study, steers were maintained in the mob grazing system (stocking density near 200,000 kg ha^{-1} moved twice per day). Stubble height was sampled as steers exited each pasture for three days prior to the beginning of the four-day study. During the study, steers were allotted the first pasture of a day at 0700 hours and a new pasture when stubble height reached the average height of the three previous days except in the 1x treatment when they were allotted only one pasture day^{-1}. This was of particular importance during the 4x and 8x treatments when steers consumed available forage very rapidly in the pastures allotted early in the day, but consumption would slow as they reached satiation.

Utilization, Trampling and Harvest Efficiency

Ten, 0.25-m^2 quadrats were randomly located within each replication of each treatment on each date. Quadrats were clipped one day prior to the pasture being grazed. Post-grazing quadrats were located 1 m north of each pre-grazing quadrat location and were clipped one day post-grazing. In each quadrat, all vegetation was hand clipped to the soil surface and litter was gathered. Vegetation was sorted as standing live herbage (SLH), standing dead herbage (SDH), litter (LIT) and trampled (TR). Samples were placed in separate, labeled paper bags, dried in a forced air oven at 60° C to a constant weight, weighed, and recorded. Trampled was identified as any live tiller that had been bent to a 45 degree angle or less from the soil surface. Biomass weights were used to calculate percent trampled, harvest efficiency, and utilization.

Percentage trampled (%) = (TR ÷ PreSLH) x 100,

Harvest efficiency (%) = [((PreSLH – (PostSLH + TR)) ÷ PreSLH] x 100,

Utilization (%) = [(PreSLH – PostSLH) ÷ PreSLH] x 100,

All calculations for utilization, percentage trampled, and harvest efficiency, were made based on a single grazing period when the data was collected. Experimental unit was one replication of each treatment within each date.

Animal Activity

Two steers in each replication were fitted with an IceCube pedometer (IceRobotics Inc. Edinburgh Scotland). Pedometers sampled animal activity at a rate of 4 hz and summarized time standing, number and duration of laying bouts, and steps taken every 15 minutes. Data were summarized and averaged as steps animal^{-1} day^{-1} for each treatment.

Analysis

Data were analyzed as a split plot in space and time. The glimmix procedure of SAS (SAS 2010) was used to analyze least squared means between treatments, dates, and years. Differences with a p-value of 0.05 or less were considered significant.

Results and Discussion

Utilization

Utilization did not differ significantly among treatments, dates, or years. Utilization was 86% of standing live vegetation in 2012 and 2013 across all treatments (Figure 3-2). Utilization was not expected to vary between treatments as relatively high utilization is common in mob grazing systems. The 86% utilization across all treatments was similar to that reported in the mob treatment of the long-term study underway on the same meadow and also that reported by other practitioners (Johnson 2012, Peterson 2014). The primary focus of this research was to determine the relative proportion of utilized SLH that was trampled compared to that consumed by grazing cattle for the four stocking density treatments.

Trampling and Disappearance

The proportion of SLH that was trampled or disappeared did not differ among treatments, dates, or years. The percent of standing live vegetation trampled was 38% for 2012 and 2013 across all treatments (Figure 3-2). The percentage of SLH that disappeared was 48% (Figure 3-2). This was not the expected result. Reports from practitioners have stated that increasing stocking densities increased their harvest efficiency (Peterson 2014), which would by default either increase utilization, or decreased the proportion of SLH trampled. Our data did not support these conclusions. One possible explanation is scale and pasture shape. Most mob grazing practitioners use herds of 100 animals or greater, some as high as 1000 animals. With larger herds, the desired stocking densities are achieved with pastures as large as one ha or more. This research used 36, and 26 steers in 2012 and 2013, respectively, requiring pastures ranging from 0.12 ha to 0.01 ha. Pastures used in this study were long, narrow pastures, approximately 90 m in length and varying width depending on the treatment. Pasture width decreased with increasing stocking density (Figure 3-1). The 4x treatment pastures were only 3.3 m and 2.2 m in width in 2012 and 2013. The 8x treatment pastures were only 1.7 and 1.1 m wide in 2012 and 2013, respectively. These narrow pastures severely limited the researcher's ability to avoid edge effect in sampling. Steers became highly expert at grazing under the portable fence prior to being moved and would impact the vegetation of a pasture prior to officially entering the pasture. It is likely that this impact affected the ability of the researcher to accurately assess the true impacts of the stocking densities within each treatment.

Animal Activity

Treatment did not significantly impact animal activity but the 2x treatment approached significantly greater daily animal activity than the 8x treatment ($0.1 > p > 0.05$) The 1x, 2x, 4x, and 8x treatments averaged 6544, 7176, 6585, and 6036 steps animal^{-1} day^{-1}. While differences were not significant, there does appear to be a non-linear response trend. The increase in activity between the 1x and 2x treatments is likely the result of an additional mid-day move to a pasture large enough to accommodate high levels of activity by animals excited by new fresh forage. The decrease in activity in the 4x and 8x treatments is likely a result of small pasture size restricting movement. Upon entering a new pasture in the 2x treatment, there is an average 15.4 m^2 or fresh pasture steer^{-1}. In the 8x treatment, there is only 3.8 m^2 of fresh pasture steer^{-1}. This low area steer^{-1} likely restricted animal movement and caused a decrease in animal activity levels. With only one year and two replications in time, standard error from the analysis of these data was quite high at 992. Adding data by repeating this study in future years may decrease standard error and allow significant differences to be detected and trends in animal activity at ultrahigh stocking densities to be more firmly established.

Conclusion

This research suggests that increasing stocking density from 108,000 kg ha^{-1}, up to 864,000 kg ha^{-1} produces no change in utilization of SLH, and no change in harvest efficiency or the percent of SLH trampled. Conclusions drawn from this research should not be considered definitive. The inconsistencies between practitioner observations and this research, coupled with the observed limitations of the small scale and pasture shape of this study, suggest that this research should be repeated on a larger scale. One of the greatest challenges faced by academic researchers is the replication of scale common in production settings. To replicate this research at a larger scale would likely require cooperation with mob grazing practitioners.

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Figures

Figure 3-1. Example of experiment design to achieve stocking density of 108,000 kg ha^{-1} (1x), 216,000 kg ha^{-1} (2x), 432,000 kg ha^{-1} (4x), and 864,000 kg ha^{-1} (8x).

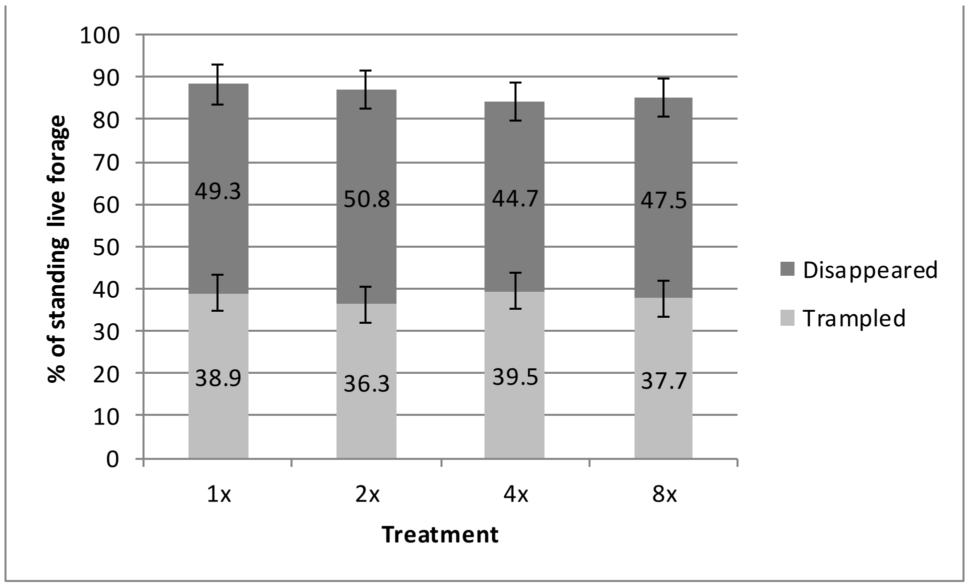

Figure 3-2. Percent of standing live vegetation utilized by trampling, and disappearance in the 108,000 kg ha^{-1} (1x), 216,000 kg ha^{-1} (2x), 432,000 kg ha^{-1} (4x), and 864,000 kg ha^{-1} (8x) treatments.

Appendix 1:

Effect of Pasture Shape on Forage Utilization and Animal Activity in Ultrahigh Stocking Density Grazing Methods

Introduction

Manipulating pasture shape has been reported to alter grazing distribution and livestock behavior. Hart et al (1993) found that smaller pastures were more evenly utilized then large pastures in both continuous and rotational grazing systems. Utilization in large pastures decreased beyond a certain distance from water. Extension publications from The University of Missouri (Gerrish and Roberts, 1999), Iowa State University (Morrical and Barnhart, 2005), The University of Nebraska (Volesky et al. 1996), South Dakota State University (SDSUCES 2007), and Purdue (Purdue Extension 2007) among others, state that square pastures tend to be more evenly utilized by livestock than long narrow pastures which tend to be underutilized at the furthest distance from water and heavily utilized near water. Most refer to this as a "rule of thumb" and do not cite any refereed literature source. Iowa State University (IASU 2005) states that square pastures allow cattle to graze in a circulatory pattern that is more natural for them than the back and forth motion required by rectangular pastures. Volesky (1996) also stated that the importance of pasture shape decreased as pastures became smaller.

A grazing experiment using sheep in Italy found that even in very small pastures (0.009 ha) grazing patterns were effected by pasture shape (Sevi et al 2001). Sevi et al (2001) found that ewes in square paddocks spent more time grazing, had greater herbage intake, and used forage more efficiently than ewes in long rectangular pastures. Pastures were divided into sampling plots near the fences (boundary plots) and near the center of the pasture (middle plots). They found that while forage utilization and intake were similar in the middle plots, ewes in rectangular pastures destroyed 42% more forage in the boundary plots than ewes in the square pastures. They recommended the use of square pastures for research studies to avoid confounding effects of pasture shape.

In mob grazing systems, pastures are quite small and grazing animals are moved through multiple pastures each day. While it seems unlikely that pasture shape would affect SLH utilization (the combined effects of trampling and consumption), the research of Sevi et al (2001) suggests that pasture shape may affect the relative proportion of SLH consumed and SLH trampled.

Study Site

The University of Nebraska - Lincoln Barta Brothers Ranch is approximately 2200 ha and located 11 km northwest of Rose, in Rock and Brown counties NE. About 100 ha of the ranch are subirrigated meadow. Approximately 10% of the 4.5 million ha of Sandhills is subirrigated meadow (Bleed and Flowerday 1998). Meadows are low, well watered, relatively level areas between elevated dune formations and can exceed a kilometer in width and several kilometers in length. Soils are fine sand well supplied with clay, silt, and organic matter, and are poorly drained. The water table is typically within 1 to 2 m of the soil surface and usually easily reached by plant roots. The Sandhills is a semi-arid region with a continental climate type and receives approximately 56 cm of precipitation annually (Bleed and Flowerday 1998).

Vegetation is a productive mixture of introduced cool-season grasses and forbs with native warm-season grasses, sedges, and rushes that typically yields 3500 to 5000 kg ha^{-1} of aboveground plant production. Dominant cool-season grasses include timothy (*Phleum pretense* L.), quackgrass (*Elymus repens* Gould), red-top (*Agrostis stolonifera*

L.), Kentucky bluegrass (*Poa pratensis* L.), and Scribner panicum (*Panicum oligosanthes* Schult. var. scribnerianum [Nash] Ferald). Native warm-season grasses include big bluestem (*Andropogon gerardii* Vitman), Indiangrass [*Sorghastrum nutans* (L.) Nash], and prairie cordgrass (*Spartina pectinata* Link). Common exotic forbs are the legumes red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.).Several species of native sedges (*Carex spp.)* and rushes (*Equisetum spp., Eleocharis spp.,* and *Juncus spp.*) are also common.

Mob grazing practitioners in the Nebraska Sandhills region typically mob graze meadows where water is plentiful and plant production is sufficient to achieve ultrahigh stocking densities in a reasonable number of moves each day. Approximately 27 ha of subirrigated meadow on the Barta Brothers ranch were designated for this study in 2010.

Materials and Methods

A six-day study was repeated twice in 2013 in each of two replications of an existing mob grazing study on The University of Nebraska – Lincoln Barta Brothers Ranch near Rose, Nebraska. Study dates were June 22nd through 27th, and July 20th through 25th. Twenty six steers were rotated through two treatments including rectangular pastures measuring 4 m by 95 m, and square pastures measuring 19.5 m^2. Each pasture totaled 0.04 ha and three pastures were grazed in each treatment each day so that 0.12 ha were grazed daily (Figure A-1). Each treatment was applied for three consecutive days in each replication. Treatments were applied in alternating order, such that while steers in the first replication were grazing square pastures steers in the second replication were grazing rectangular pastures and vies-versa. This allows each treatment to be executed in each replication and comparisons of treatment effects to be made within dates between replications.

Utilization, trampling, and harvest efficiency

The first day within each treatment was considered an acclimation period and no sampling occurred. The second and third day of each treatment, seven 0.25-m^2 quadrats were randomly located within each replication of each treatment on each date. Quadrats were clipped one day prior to the pasture being grazed. Post-grazing quadrats were located 1 m north of each pre-grazing quadrat location and were clipped one day post-grazing. In each quadrat, all vegetation was hand clipped at the soil surface and litter was gathered. Vegetation was sorted as standing live (SL), standing dead (SD), litter (LIT) and trampled (TR). Samples were placed in separate, labeled paper bags, dried in a forced air oven at 60^o C to a constant weight, weighed, and recorded. TR was identified as any aboveground live biomass in which the tiller had been bent to a 45 degree angle or less from the soil surface. Biomass weights were used to calculate percent trampled, harvest efficiency, and utilization.

Percentage trampled (%) = (TR ÷ PreSL) x 100,

Harvest efficiency (%) = [((PreSL – (PostSL + TR)) ÷ PreSL] x 100,

Utilization (%) = [(PreSL – PostSL) ÷ PreSL] x 100,

All calculations for utilization, percentage trampled, and harvest efficiency, were made based on a single grazing period when the data was collected. Experimental unit was one replication of each treatment within each date.

Animal Activity

Two steers were randomly selected within each replication and fitted with an IceCube pedometer (IceRobotics Inc. Edinburgh Scotland). Pedometers sampled animal activity at a rate of 4 hz (4 samples second^{-1}) and summarized time standing, number and duration of laying bouts, and steps taken every 15 minutes. Data were summarized and averaged as steps animal^{-1} day^{-1} for each treatment.

Analysis

A split plot design was used for this study with replication (MOB 1 vs MOB 2) being the main plot and date (June vs July) as the sub plot. Data were analyzed using the lsmeans statement within the glimmix procedure of SAS (SAS 2010). Differences with p-values of 0.05 or less were considered significant.

Results and Discussion

Utilization, trampling, and harvest efficiency

There were no significant differences between treatments or dates in percent standing live vegetation that was utilized, trampled, or disappeared (Figure A-2). Utilization, trampled, and disappeared vegetation averaged 86.9, 50.6, and 36% respectively across treatments and dates. This was not the expected effect. Based on the results of Sevi et al (2001), the square pastures were expected to have greater harvest efficiency and lower trampling of standing live vegetation. Numerically, the square pasture had 5% less trampling and 3.5% greater disappearance than the rectangular pastures, but standard error was too high to detect significance. High standard error was not unexpected as the study was only repeated twice in time with only two replications each time. Additional replications of the study in future years, may yield significant results. It is also possible that, as stated by Volesky et al (1996), the impact of pasture shape on grazing distribution and SLH utilization is lessened in small pastures. If true, this would likely be most evident in a mob grazing scenario with its very small pastures, ultrahigh stocking densities and rapid rotation.

Animal Activity

Animal activity was significantly lower in square pastures than in rectangular pastures. Steers in the square pastures averaged 5352 steps day^{-1} which was 11% less than the 6021 steps day^{-1} taken by steers in rectangular pastures (Figure A-3). The difference in animal activity is likely the result of several factors. As steers enter a rectangular pasture, the narrow 4 m width forces them to move a greater distance to become evenly dispersed across the pasture. Square pastures on the other hand require much less travel distance to disperse evenly across the same area. Distance from water may also be a factor. Average distance from water in the rectangular pastures was 47.6 m compared to only13.8 m in the square pastures. Square pastures reduced the average distance to water by 71%. Pasture shape did not significantly impact disappearance of standing live vegetation which can be used as an estimate of animal intake. While intake was not significantly impacted by pasture shape, a decrease in activity equates to decreased energy output by the animal. Decreased energy output equates to decreased nutritional requirements and increases the likelihood that the animal will gain condition on a given ration.

Conclusion

With only one year and two replications, this study is far from decisive, but some conclusions can be made. Square pastures decrease animal activity compared to rectangular pastures. This reduction did not produce significant differences in the proportion of vegetation that was trampled or consumed by steers in the first year of the study, but these differences may become significant as more replications are added in time. Reduction in animal activity without a change in intake should result in an increase in animal performance over time. Animal performance is one of the determining factors of production and profitability for ranchers. It is possible that even at very high stocking densities common in mob grazing systems, square pastures could prove to be more profitable for producers in the long term.

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Figures

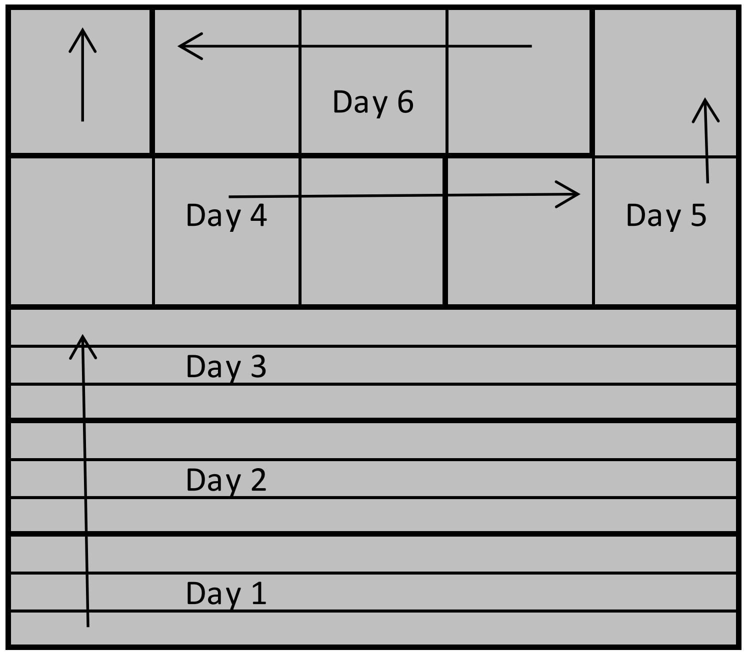

Figure A-1. Example of treatment design. Rectangular pastures (days 1-3) then square pastures (days 3-6) at 4 pastures day^{-1}. Arrows show direction cattle were moved through pastures. Replication rotation was opposite (square pastures first, then rectangles)

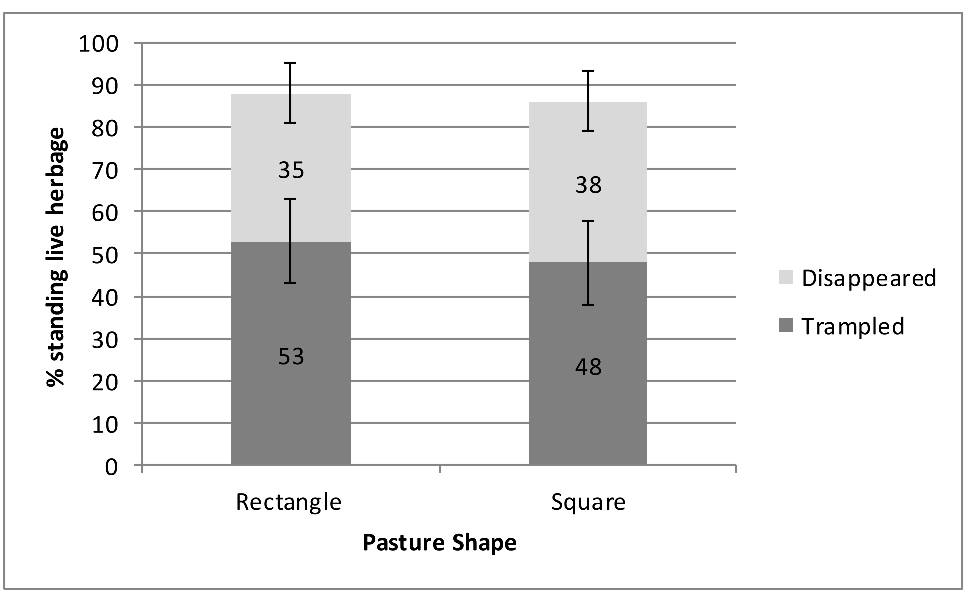

Figure A-2. Utilization, trampling and disappearance as percent of standing live herbage in square and rectangle pastures.

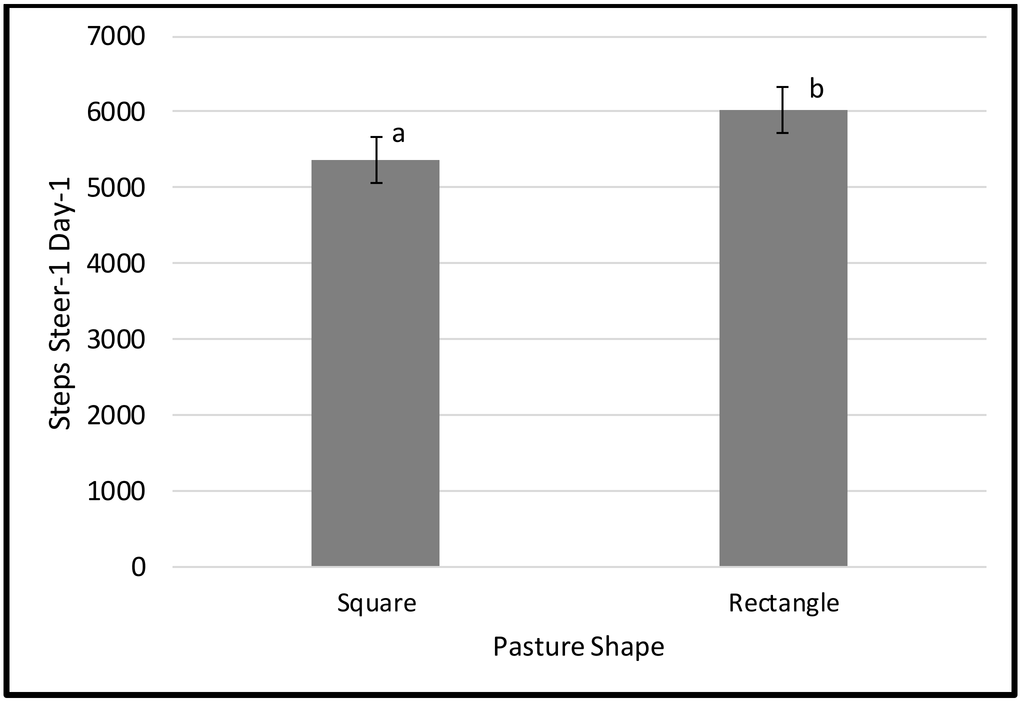

Figure A-3. Steps steer^{-1} day^{-1} in square and rectangle pastures. Between treatment, different letters significantly differ.